

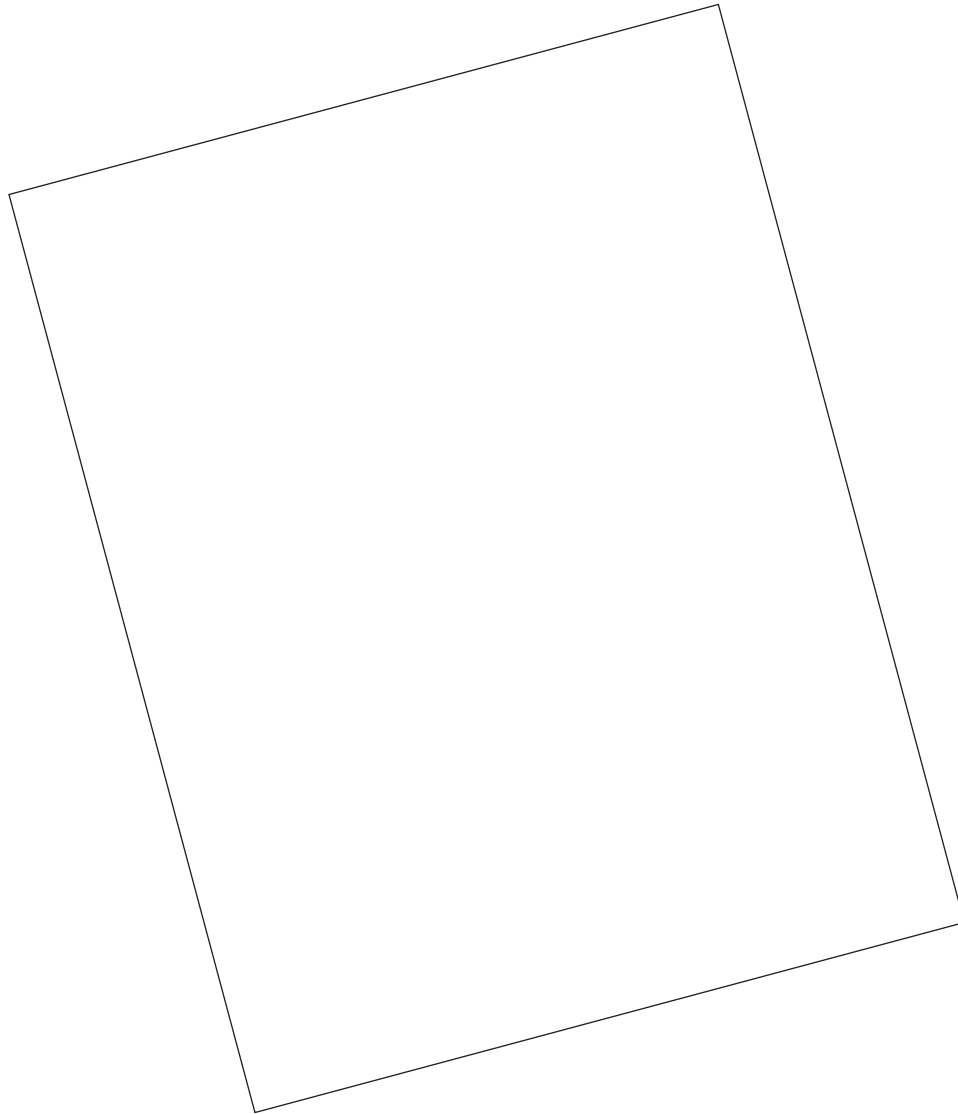
***Evaluation of Compressed  
Natural Gas (CNG)  
Fueling Systems***



**OCTOBER 1999**  
**CALIFORNIA**  
**ENERGY**  
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**Gray Davis, Governor**

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## CALIFORNIA ENERGY COMMISSION

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## EXECUTIVE SUMMARY

The objective of this study is to assist the Transportation Technology and Fuels Office (TTFO) of the California Energy Commission (Energy Commission) and the Technology Advancement Office of the South Coast Air Quality Management District (SCAQMD) in reviewing and assessing various compressed natural gas (CNG) fueling systems and related key issues. Based largely on a telephone survey of industry experts and station end users, this report provides an evaluation of key barriers to expansion of the CNG infrastructure and how government funding can best be applied to overcome those barriers.

The CNG refueling industry consists of numerous companies that design and install a wide variety of non-standardized, application-specific refueling systems. Virtually all CNG stations are custom built to match site parameters (especially the so-called “suction” pressure of the natural gas line), often resulting in unnecessarily costly facilities. The high cost of CNG fueling stations compared to conventional petroleum stations presents a major barrier to expansion of the NGV refueling infrastructure. Government agencies can help by focusing funds and efforts on the installation of CNG stations where station customization can be minimized. Procurements for CNG stations should focus on simple performance specifications that essentially seek the lowest-cost quality CNG that can be reliably delivered to a given number of vehicles in a given amount of time.

CNG stations range from single-hose time-fill facilities to very complex fast-fill stations that fuel hundreds of vehicles per day with thousands of “gasoline gallon equivalents” (GGE) of CNG. The most important factor in achieving long-term success with CNG stations (good performance, low life-cycle costs, and high customer satisfaction) – especially as they increase in complexity and cost -- is choosing the right company to oversee their design, packaging, installation, and long-term servicing. Failure to use experienced, qualified vendors with a long-term commitment to the industry can result in stations that are financial disasters and virtually unusable. Based on past problems, it is recommended that future competitive procurements for CNG stations avoid using low bid as a major selection criterion. Careful due diligence should be performed to verify engineering credentials and financial balance sheets of all bidders.

A major goal of the NGV industry has been to increase the current low utilization of existing CNG stations by building new public-access stations. However, the incremental cost of building fast-fill stations that meet applicable codes and standards for public access can be extremely high. As long as there is low overall demand for CNG fuel, industry executives cannot achieve the necessary return on investment to justify major capital expenditures in public-access stations. Given this problem, the best use of government resources may be to support new installations in applications

that will deliver the most “bang for the buck” towards a sustainable CNG market, i.e., large on-site fleets that use thousands of GGE per day.

More work must be done to reduce capital costs at CNG stations by standardizing station designs and components. Dispensers are second only to compression equipment as the most expensive part of a CNG fueling station, with gas flow meters accounting for much of the high cost. Part of the problem is that CNG dispensers intended for public-access stations must meet challenging and expensive Weights and Measures regulations that may not be fully germane for gaseous fuels. Government agencies with vested interests in expansion of the CNG infrastructure should work with the dispenser industry and W&M officials to investigate this further.

Card lock systems that control dispenser access and record and process NGV fueling transactions are available with many levels of sophistication. Efforts such as the FuelNet pilot program are underway to develop a national networked system with card reader commonality among CNG stations. The California NGV Coalition is now working with vested interests to integrate California stations into the FuelNet system. Despite these various efforts, executives from the CNG fuel card industry indicate that the market for CNG fuel must be greatly expanded before they are willing to invest the necessary capital to make a universal card reader system.

The price of CNG fuel has been stable and generally not a factor in the satisfaction or dissatisfaction of fleets with NGVs and CNG fueling stations. Of much greater concern are the high costs of operating and maintaining station equipment. Much more work needs to be done to assist fleets in selecting the best-suited equipment for their intended application, and implementing a comprehensive preventative-maintenance program that will ensure good station reliability for its useful life. The most fundamental equipment choice is whether to use an electric motor or an internal combustion engine as the prime mover to power gas compression. Both options offer certain advantages and disadvantages, but for most mainstream CNG stations and NGV applications, electric motors appear to be the most cost-effective choice. For larger CNG stations with high gas throughput where a rigorous preventative maintenance program is in place, high electricity costs for electric motor drive may make natural-gas-engine drive the more attractive choice. However, a major downside of engine prime movers can be the expense, time and difficulties associated with air quality permitting and compliance.

Compressor oil carryover from CNG fueling stations remains a significant but manageable problem in the NGV industry. High oil concentrations (well above 200 ppm) have occurred at some CNG stations, causing NGV pressure regulators and valves to fail, and on-board CNG storage tanks to partially fill with oil. For most fast-fill CNG stations of mainstream size (200 to 300 scfm), the best oil-control solution appears to be the use of well-engineered lubricated compressors in tandem with synthetic polyalkylene glycol (PAG) oil and coalescing filters. “Non-lubricated” compressors are also available that effectively control oil carryover, although further documentation of ring life and other durability factors may be needed to compare life-cycle costs with lubricated compressors. It is recommended that prospective packager/installers of CNG stations be required to describe in detail the equipment, techniques and technologies they will employ to control oil carryover, and demonstrate their effectiveness.

At some CNG stations with insufficient gas-drying equipment, water vapor in the fuel or ambient air has created problems such as icing of NGV regulators during fueling. However, the bigger issue to station operators has been gas dryers themselves, which can have high operating costs, pose hazardous waste disposal issues, and cause significant station downtime. It is not uncommon for gas-drying systems to be bypassed by users or installer/packagegers, but such a decision can have significant cost implications and should be made by experts only. Inadequate training and knowledge about gas dryer systems on the part of station end users has exacerbated these problems. Even large fleets with trained on-site maintenance personnel have experienced costly problems, especially with high-pressure twin tower dryer systems at high-throughput facilities.

Better preventative maintenance programs are badly needed to reduce the down time and life-cycle costs associated with compressors, gas dryers, and other station components. However, many fleets simply don't have the appointed people to maintain a complex fueling station, and affordable maintenance agreements on existing stations can be difficult to find. If possible, government resources should be used to help existing and future end users of CNG stations obtain comprehensive maintenance agreements with skilled and reputable companies to maintain CNG stations.

In recent years several "turnkey" CNG providers have been emerging that essentially sell natural gas compression services to customers with high fuel use. These fuel providers are willing to manage all aspects of a CNG facility's installation, operation, and maintenance, in exchange for an agreement by the customer to purchase a minimum volume of fuel for a set period of time. Whenever possible, fleets should seek these fixed-price (inflation included) commitments because they shift the risk and uncertainty associated with CNG station operation and maintenance to trained, expert entrepreneurs. Virtually all the major problems that fleets have experienced with CNG stations can be addressed through these arrangements, and the customer can realize major savings over the long run. Government agencies should encourage and assist such arrangements as much as possible, and explore pooled fuel demand for smaller fleets to meet the minimum fuel-purchase requirements of turnkey companies.

In general, lack of knowledge about CNG stations by users contributes significantly to high station life-cycle costs, and hinders wider implementation of the CNG refueling infrastructure. It is recommended that government funding and resources be used to improve the knowledge of existing and prospective end users of CNG stations. Two suggested mechanisms are 1) encouraging/arranging user attendance at educational forums on CNG stations, and 2) use of companies that specialize in independent assistance to fleets in specifying, bidding, selecting and even operating CNG stations.

## SECTION 1 – INTRODUCTION AND BACKGROUND

### 1.1 STUDY OBJECTIVE, METHODOLOGY AND LIMITATIONS

The objective of this study is to assist the Transportation Technology and Fuels Office (TTFO) of the California Energy Commission (Energy Commission) and the Technology Advancement Office of the South Coast Air Quality Management District (SCAQMD) in reviewing and assessing various compressed natural gas (CNG) fueling systems and related key issues. This will enable staff to evaluate future proposals and incentive programs involving CNG stations with expanded knowledge and help ensure that future funding efforts are expended towards the most efficient, cost-effective and durable systems possible.

The CNG refueling industry builds and installs a wide variety of non-standardized, application-specific refueling systems. Each system consists of many individual components and subsystems, including compressors, prime movers, gas dryers, gas storage, dispensers, card readers, and other key system components. Virtually all CNG stations are custom built according to site parameters, the intended application, the needs of the user fleet, and standard business practices of the installer/packager. It is therefore beyond the scope of this study to perform a comprehensive evaluation of CNG stations. Rather, this study attempts to provide up-to-date, useful information about the most commonly used CNG fueling station systems and equipment, with a focus on key barriers that hinder expansion of the CNG fueling infrastructure.

Sources used to complete this study include published documents, industry brochures, internet web sites, and most prominently, telephone conversations between ARCADIS Geraghty & Miller and a wide variety of individuals involved with the CNG fueling station industry (either builders / installers / packagers or end users).<sup>1</sup> In some cases people responded on the condition that they remain anonymous. This report presents an overview of the current state-of-the-art for CNG stations, based on a cross-section of expert opinion and industry information.

### 1.2 OVERVIEW OF BARRIERS TO COST-EFFECTIVE CNG STATIONS

A key barrier to wider deployment of an NGV infrastructure is the relative cost of CNG fueling stations compared to conventional petroleum stations. Specific problem areas that all contribute to the higher cost of CNG stations include immature fuel metering and transfer technologies, low station utilization, and lack of equipment standardization. Efforts to reduce the relatively high cost of CNG fueling stations were significantly set back when the California Public Utilities

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<sup>1</sup> Abbreviated source listings are provided in footnotes, with complete references provided in Appendix B.



Commission rejected proposed rate-based NGV programs from the utilities, of which the fueling infrastructure was a key component.

The Gas Research Institute (GRI) and other organizations in the industry have extensively assessed major barriers – technological, economic and institutional – to expansion of the CNG fueling network. Today’s CNG fueling stations are functional, but they must be made more economical through significant improvements in equipment reliability, durability, throughput capacity, simplicity, and standardization. GRI’s NGV Infrastructure Working Group (NGV-IWG) has recommended the following industry technical goals to address the barrier of fuel station economics: 1) optimal, modular station size; 2) standardized compressors; and 3) improved metering / dispensing strategies.<sup>2</sup> Unfortunately, GRI’s efforts to pursue technology and product development for NGV fueling stations have met with limited success. This is because “Many of the market participants are unable or unwilling to undertake significant R&D efforts.”<sup>3</sup> One objective of this study is to obtain better insight into the dynamics of this problem.

### 1.3 OVERVIEW OF THE CNG FUELING STATION INDUSTRY

The CNG fueling station industry consists of numerous companies that perform or arrange the design, packaging, permitting, and construction of complete CNG stations. Some of these companies manufacture the individual components in their systems, such as compressors and dispensers, while others serve only as “packagers” of components manufactured by a diversity of vendors. Many companies team with general and specialty contractors to perform the complete process of engineering and constructing CNG stations. Recently, several “turnkey” CNG providers have been emerging that essentially sell natural gas compression services to their customers. These fuel providers are willing to manage all aspects of a CNG facility’s installation, operation, and maintenance, in exchange for an agreement by the customer to purchase a minimum “throughput” of fuel for a set period of time.

The result of this industry diversity is that individual fleet users are faced with a plethora of complex choices if they pursue access to CNG fuel. These options can be very difficult to evaluate, even for individuals with a working knowledge of the issues, and establishment of common parameters is challenging. The following table provides a partial list of companies involved in key capacities with the CNG station industry. Appendix A (Tables A-1 through A-12) summarizes the views and comments of surveyed end users about CNG systems that were manufactured or packaged by these various industry players. The most important aspects of all these tables are drawn out in the text and discussed in greater detail.

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<sup>2</sup> At the time this report was being finalized, the NGV-IWG was scheduled to meet in Las Vegas. Many of the issues identified in this study were on the agenda for discussion. It is expected that approximately \$3.7 million will be allocated through the NGV-IWG to further address CNG station barriers.

<sup>3</sup> Bill Liss, Gas Research Institute, personal communication to Jon Leonard.

Primary Functions of Selected Companies Involved in the CNG Station Industry				
Company	Contact	Equipment / Manufacturing	Packaging / Installation / Maintenance	Turnkey Fuel Provider
ANGI International	Curt Grimmer (800) 955-4626	√		
Bauer Compressors	Merv Bohrer (757) 855-6006	√		
Fleet Star	Don Ryan (800) 723-9398		√	√
FuelMaker Corp.	Paula Hebert (925) 706-7633	√	√	
Gemini Engine Co.	M.B. Parks (800) 242-3219	√		
Hurricane Compressors	Curt Grimmer (800) 955-4626	√	√	
IMW Atlas Industries	Dave Postuma (760) 940-8605	√	√	
Kraus Alternate Fuels	Willie Romero (204) 988-1203	√	√	
Natural Fuels Corp.	Kimberly Myers (415) 543-5654	√	√	
P.C. MacKenzie	Mark W. Good	√	√	
Penn Wilson Technologies	Not Available	√	√	
Pickens Fuel Corp.	Jim Harger (888) 732-6487		√	√
Pinnacle CNG Systems	Drew Diggins (915) 686-7002	√	√	√
Sulzer USA	Hank McElvery (602) 391-0912	√	√	
Trillium USA	Jan Hull (801) 531-1166	√	√	√

## SECTION 2 – STUDY FINDINGS AND RESULTS

The following narrative describes findings from ARCADIS Geraghty & Miller’s search of recent literature about CNG fueling systems and our discussions with knowledgeable industry people and CNG users. Information about station equipment and various subsystems is presented in the context of specific barriers to expansion of the CNG infrastructure. Conclusions and recommendations for each topic/barrier/issue are presented in Section 3.

### 2.1 STATION STANDARDIZATION AND MODULARITY

Equipment and design standardization for CNG stations has been identified as a critical goal to reduce costs and expand the infrastructure. Today’s stations are designed more like utility plants than commercial products, and virtually every station has unique attributes. As a result, it has been difficult to reduce hardware costs. GRI has estimated that design standardization could reduce the cost of a station by 50% or more. For several years GRI, the Department of Energy, and other agencies have targeted development of two or three optimized, standard-capacity fueling station designs or modules. Among the many challenges would be the need to synchronize this effort with the anticipated short- and long-term growth of the NGV market.<sup>4</sup>

ARCADIS Geraghty & Miller contacted numerous people in the industry to assess the status of efforts to standardize CNG fueling stations. A consensus is that the process to standardize has been initiated, but very little tangible progress has been achieved. Some skid-mounted stations now have common design, and this has helped reduce costs to a limited extent. However, stations are still built “from the ground up” in customized fashion, with little commonality of parts. A key goal – to reduce the number of compressor choices that an NGV fueling station operator must consider – has been elusive. Current compressor technology is not the barrier – rather, it is the lack of commercialized “standard” compressors that can operate on the majority of natural gas supply lines and provide adequate compression services for the intended NGV market.<sup>5</sup>

The underlying problem is that today’s CNG stations are typically customized according to the intended use and key site parameters – most notably, the gas inlet pressure (known as “suction” pressure), which can vary from one psi up to 500 psi. Attempts to “cookie cutter” installations as if they are standardized can lead to bigger problems. For example, compressors that require a suction pressure of 60 psi have been installed in areas where only 35 psi was readily available. The extra load that resulted for the compressors caused overheating in the first stage of compression. Attempts to cool the compressors with external misting resulted in harmful corrosion of the compressor housings.<sup>6</sup>

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<sup>4</sup> GRI, *Report on National NGV Infrastructure*, August 1998.

<sup>5</sup> Ibid.

<sup>6</sup> This information was provided by an executive at a turnkey company, who asked to remain anonymous.

Other major site variables that lead to customization include space limitations and environmental considerations (emissions and noise). Finally, stations are customized to meet user parameters such as intended vehicle application, size of fleet, and type of prime mover desired. The upshot is that some customization is essential to design an efficient and durable CNG station, but too much can result in an overly costly station that has more capability than necessary.

Achieving greater station standardization is a major challenge for the CNG industry. CNG fueling stations are much more complex than those for gasoline and other liquid fuels. Standardization of CNG stations and components may require capital and resources that greatly exceed those of the relatively small CNG industry. Individual companies have carved out market niches within this variation (e.g., high or low suction pressures), further hampering progress to standardize the industry.

The CNG industry has been urged to take action by initiating an industry-accepted set of “Recommended Best Practices” for designing fuel stations, with the NGV-IWG leading the effort. It has been suggested that the NGV-IWG should survey every currently installed CNG fueling station in North America “to discover a consistent set of facts” about key station characteristics. However, given the number of variables and the difficulty locating people with comprehensive knowledge about a given CNG fueling station (discussed further below), this would be a large and very challenging task.

Closely related to the issue of station standardization is *modularity*. This refers to the ability to increase the throughput and/or utility of an existing station by retroactively adding new equipment and fueling capacity. This would allow smaller-capacity stations to be built at lower cost, with the intent to expand capacity later as throughput increases. The development of modular stations is therefore a key goal for the NGV-IWG.

Some fueling station components are already at least partially modular, and stations can be designed accordingly. For example, gas storage for fast filling can be increased by adding “3-packs” of ASME storage vessels, assuming the requisite space is available at the site. Fueling islands can be built with space for a second dispenser to be added in the future. Dispensers are becoming more modular through weights and measures requirements. However, the most important area to target greater modularity is gas compression. For low-flow, low-suction-pressure applications, FuelMaker’s Quantum line of Vehicle Refueling Appliances can be manifolded to add more flow capacity at a later date. To a limited extent, other compressor systems allow this option as well. More work needs to be done to develop a common design for these small stations. However, the type of modularity most needed by the industry is a mainstream fast-fill CNG station of medium size (100 to 300 scfm) that can easily be augmented for greater throughput and capacity. This could be achieved through modular, prepackaged compressor units that could allow scaled-down initial installation costs with the prospect for field upgrades if station demand increases.

The CNG station industry is increasingly attempting to build CNG fueling stations in a modular fashion, with the expectation to add greater storage and dispensing capabilities at a later date.

However, major advancements in modularity may not be practicable due to the large variation in suction pressure, which affects key parameters such as compressor size and dryer type.

## 2.2 IMPORTANCE OF WELL PACKAGED, INTEGRATED AND MAINTAINED SYSTEMS

As described above, site-by-site customization is the norm for CNG stations, and there is little use of standardized components. Mistakes can result in big problems and high costs. The role of the packager/installer/system integrator is extremely important. From beginning to end, the complete process to build a new CNG station requires a great deal of planning time, effort and engineering expertise. Compressors must be integrated with the package components, including the structural skid, a prime mover (motor or engine), piping, pulsation control, cooling systems, dryer equipment, process valving, and control systems. A single entity is needed to oversee the station installation and take full responsibility for its start up and initial operation. Once operational, CNG stations require ongoing service and troubleshooting, and it is essential that one party is available to resolve problems quickly. Thus, the success of a CNG station (good and reliable performance, low life-cycle costs, and a satisfied customer) largely depends on picking a company with sound business and engineering credentials to plan and oversee its design, packaging, installation, and long-term servicing.

Unfortunately, major problems with some CNG stations have directly resulted from the use of installer/packager outfits that were either unwilling or unable to properly design and install cost-effective, relatively trouble-free facilities. Certain companies have bid jobs for which they purport to comply with detailed specifications or requirements, but in reality they do not. This has enabled them to significantly underbid other companies that put greater emphasis on quality and durability. Some low-bid packager / installers have won major procurements only to be out of business a few years later. For example in 1995, South Coast Area Transit (SCAT) purchased a CNG station packaged by Wilson Technologies for approximately \$200,000 less than the next-lowest bid.<sup>7</sup> From the beginning, SCAT had major problems with the engine drive of the system, as well as other issues. SCAT is seeking resolution but Wilson Technologies is no longer in business. OmniTrans in San Bernardino and UPS in Hartford Connecticut also bought Wilson-packaged systems that have had major problems. This illustrates the importance of working with an installer/packager that is “in it for the long haul.” However, it is also important to note that the CNG industry is relatively new (at least for vehicle applications) and all the various players – including the turnkey companies, compressor manufacturers, engine manufacturers, and end users – are still experiencing a steep learning curve with CNG technologies.

Based on some of the problems in the past, many people who are familiar with the CNG station industry strongly recommend that future solicitations avoid using low bid as a major selection criteria. Procuring reliable long-term access to CNG fueling is a very good example of the old adage: “You get what you pay for.” Over the long run, packager / installers that consistently

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<sup>7</sup> Peter Drake, SCAT General Manager, personal communication to Jon Leonard.

come in at low bid probably do not offer the most cost-effective alternative for CNG fueling, and in the worse-case scenario they may be out of business only months after installing a station with inferior equipment. To ensure that companies are in the CNG station business for the long term, bidders should be required to provide verifiable financial information and balance sheets. Packager/installers should be asked to provide a detailed list of employee experience and every station installed over the last five years, with an emphasis on California installations.

Also critical during the station procurement process is the establishment of performance specifications, especially the customer's expectations for 1) refueling times and capacities as a function of fleet characteristics, 2) start up of the facility, and 3) the performance of essential maintenance items over the life of the station. Effective specifications and startup requirements can be simple and relatively brief (see Section 3).

As mentioned above, it is becoming more common for turnkey CNG providers to execute agreements with large fleets to provide complete on-site service, maintenance and personnel training for their CNG customers, who in turn agree to purchase a minimum amount of fuel for a set period of time. Additional discussions about how this type of arrangement effects the crucial issues of station maintenance and life-cycle costs are provided in subsequent sections of this report.

## 2.3 PUBLIC-ACCESS STATIONS AND FUEL THROUGHPUT

Expansion of the NGV market will depend on a significant increase in the numbers of both private fleet ("onsite") and public ("open-access") fueling stations, in tandem with a major increase in NGV demand. The common need for both station types is high fuel throughput. Despite the focus on compressors and other equipment issues, low utilization of CNG stations is the biggest barrier to the near-term economics of an NGV fueling infrastructure.<sup>8</sup> A sustainable NGV market must be founded on attractive fuel prices for customers and sufficient return on investment for station owners – neither which are likely to occur without maximizing the amount of fuel passing through the station on a daily basis.

The required investment to build new public-access stations is significant. The incremental cost of building a station that meets applicable codes and standards for public access can be as much as \$150,000.<sup>9</sup> Among other reasons, such stations must meet challenging weights and measures requirements for dispensers (discussed further below). Entrepreneurs have little incentive to build new public-access stations or upgrade on-site stations, because demand for CNG fuel is much lower than the industry anticipated five years ago.<sup>10</sup> As long as there is low fuel throughput, industry executives have little or no incentive to make capital investments in public-access stations. The risk to invest in a public station can be high even when a large private fleet is willing to serve as an "anchor" customer. Ironically, some entrepreneurs fear that the anchor fleet will eventually

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<sup>8</sup> GRI, *Report on National NGV Infrastructure*, August 1998.

<sup>9</sup> This information was provided by an executive at a turnkey company, who asked to remain anonymous.

<sup>10</sup> According to various GRI documents.

obtain government grant money to build its own CNG station, resulting in a major sudden loss of throughput at the public station. In sum, the CNG entrepreneurs will not seriously commit to the public CNG station market until normal profit incentives compel them to do so.<sup>11</sup>

ARCADIS Geraghty & Miller received numerous suggestions from industry representatives about what government officials can do to help this situation. One suggestion was that government agencies with a vested interest in expansion of the NGV market should work with state and local Weights and Measures officials to devise requirements that are more favorable to gaseous fuels. However, others stressed that government agencies should let market forces resolve issues regarding public stations; they believe that the best use of limited government funds is to assist large private fleets in obtaining on-site CNG stations. A good example is the Pinnacle-built UPS facility in San Ramon, where nearly 4,000 gasoline gallons equivalent (GGE) of CNG per day are pumped (see Table B-9).

## 2.4 FUEL QUALITY

Pipeline natural gas in California consists principally of methane (90+ percent) with small amounts of inert gases, water vapor, odorants, ethane, propane, butane, higher hydrocarbons, and other species. The processes of compressing pipeline gas and storing it as CNG results in additional composition changes that, in worse cases, can adversely affect CNG fueling station operation and NGV performance. Three primary types of contamination are of concern: 1) oil carryover from the compressor system, 2) moisture, and 3) non-methane hydrocarbon species. ARCADIS Geraghty & Miller surveyed industry experts and station users of various systems to determine the current extent of these problems.

### 2.4.1 Compressor Oil Carryover

It is well documented that oil from CNG fueling stations can be entrained in CNG streams and deposited in NGV tanks and fueling systems. According to a study performed by GRI and AGA, “in isolated cases, deposits of compressor oil have been observed in amounts large enough to create significant liquid deposits in fuel cylinders and to interfere with the operation of pressure regulators, valves, and other onboard components.”<sup>12</sup> Fuel injectors, metering systems and second stage regulators in particular tend to accumulate oil, and can be adversely affected. The potential also exists for vehicle emissions to be adversely affected when oil is introduced into an NGV engine, although this has not yet been quantified.<sup>13</sup> On the other hand, CNG is a very dry fuel, and some oil carryover is necessary to provide lubrication for certain engine parts.

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<sup>11</sup> This paragraph reflects a composite opinion expressed by executives from several different companies with market interests in the CNG station industry.

<sup>12</sup> GRI-96/0028 Topical Report, *Gas Composition Issues and Implications for Natural Gas Vehicles and Fueling Station*.

<sup>13</sup> We spoke to ARB’s Paul Hughes and Steve Albu (El Monte) as well as Jose Gomez (Sacramento), none of whom were aware of data showing that oil carryover significantly affects the emissions of CNG vehicles. However,

Oil carryover has been vaguely addressed in the California Air Resources Board's (ARB's) Title 13 specification, which states that "CNG shall not contain dust, sand, dirt, gums, oils, or other substances in an amount sufficient to be injurious to the fueling station equipment or the vehicle being fueled." Similarly, Society of Automotive Engineers (SAE) standard J1616 states the following:

"Additional data are required to determine acceptable lubricating oil levels as well as standardized test procedures for quantifying lubricating oil content. However, it must be understood that levels adversely affecting NGV performance are unacceptable by definition."

Fueling station-derived oil carryover depends upon many variables, including compressor design and mechanical condition; operating parameters (e.g., load, temperature and pressure); the type and amount of oil used; the number of compression stages; and the presence or absence of filtration devices. For effective control of oil carryover it has been necessary to employ a variety of techniques and technologies involving these parameters. These include properly sizing and maintaining equipment; and using compressors with improved head design, inter-stage cooling, coalescing filters, and synthetic oils. In appropriate applications, "non-lubricated" compressors can be used.

ARCADIS Geraghty & Miller surveyed many people involved in the NGV industry (e.g., users, fuel suppliers, vehicle manufacturers, equipment makers, and CNG station packagers) to determine if the problem is being managed in the field. In a telephone survey of approximately 40 CNG station users, most were not aware of any problem from compressor oil carryover (some exceptions are discussed below). However, industry representatives and NGV manufacturers are very aware of the issue, and indicated that oil carryover remains a real -- but manageable -- problem. The following provides more detailed findings on this issue and the various efforts to control it, including the impact of oil carryover on NGVs.

Lubricated compressors – Many mainstream CNG stations use lubricated reciprocating compressors such as those made by Ariel, which are widely regarded as being among the most durable and best-performing CNG compressors in the world. Like other compressors of similar size and type, Ariel compressors have reportedly had past problems with oil carryover.<sup>14</sup> This problem has been partially mitigated with improved compressor maintenance and the use of properly sized and maintained coalescing filters, among other strategies. Filters as small as ¼ micron have been used that help trap oil in aerosol form. However, coalescing filters must be maintained and replaced at intervals that increase with gas throughput, and smaller filters require more frequent attention. Also, coalescing filter sumps contain liquid oil mixed with trace amounts of hazardous wastes such as benzene and PCBs. This results in disposal issues. It appears that

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industry representatives such as Bruce Johnson of Impco believe that there is a correlation.

<sup>14</sup>Examples include LACMTA, which performed a test to determine the source of oil contamination in its CNG buses. According to Warren Fu, the oil source was not the CNG compressor system, but the validity of the test methodology is uncertain.



using coalescing filters alone in Ariel compressors (and other similar lubricated types) may not reduce oil carryover below problematic levels, and the necessary process to properly service and maintain the compressor and filtration system can be costly and labor intensive.

Part of the problem is that oil vaporized by high compressor temperatures does not coalesce. Since about 1992 several compressor manufacturers have been advocating the use of synthetic polyalkylene glycol (PAG) oils because they produce carryover oil only in the aerosol form, which is more easily removed by coalescing filters than oil vapor. Synthetic oil is significantly more expensive than mineral oil – from \$19 to \$25 per gallon compared to about \$5 per gallon – but it reportedly lasts three times longer than mineral oil and is easier to maintain.<sup>15</sup>

According to a GRI study,<sup>16</sup> tests performed with PAG oil resulted in virtually no vapor-phase carryover oil. These results, which appear to be verifiable in the field, suggest that use of synthetic PAG oil in combination with coalescing filters can provide an effective control strategy for mitigation of oil carryover. ARCADIS Geraghty & Miller's informal survey of CNG station users with Ariel compressors indicated that some, although not all of them, use PAG synthetic oils.

Sulzer also makes large reciprocating CNG compressors. Sulzer claims to have reduced oil carryover through its trunk piston engine design and an effective inter-stage cooling system, and guarantees less than 0.5 lbs. of oil carryover per million scf of CNG.<sup>17</sup> Sulzer also guarantees a minimum ring life of 6,000 hours for its compressors, while claiming to typically achieve 10,000 to 12,000 hours. Like Ariel compressors, Sulzer compressors generally have a reputation in the industry for being superior products, although they carry a premium price. Certain installer/packagegers prefer Sulzer compressors largely because they find the inter-stage cooling system to be well engineered and effective at keeping the gas temperature below the point of oil vaporization, resulting in very low oil carryover.<sup>18,19</sup> However, other industry insiders are skeptical that the ring life for Sulzer compressors in real-world operation will meet the claimed 6,000 to 12,000 hours.

According to surveyed end users, Gemini compressors have exhibited high oil carryover at certain installations, with mixed success in controlling the problem. South Coast Area Transit (SCAT) has been able to mitigate oil carryover from its Gemini compressors using coalescing filters made by Owata, although a careful, regular maintenance regime is required.<sup>20</sup> OmniTrans in San Bernardino purchased a system from Wilson Technologies several years ago featuring two 650 cfm Gemini compressors (the model number was unknown to the person surveyed). Oil carryover has been so excessive from these two compressors that the high-pressure valves on the CNG buses

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<sup>15</sup> Brett Freeman, Royal Lubricants, personal communication to Jon Leonard.

<sup>16</sup> GRI-96/0028 Topical Report

<sup>17</sup> From Sulzer brochures. Sulzer apparently does not offer a field technique for measurement of oil carryover.

<sup>18</sup> Greg Dahl, FleetStar, personal communication to Jon Leonard.

<sup>19</sup> Mark Haught, Southwest Gas Company, personal communication to Jon Leonard.

<sup>20</sup> Peter Drake, personal communication to Jon Leonard,

failed, and significant amounts of oil were found in the on-board storage tanks.<sup>21</sup> Checker Cab in Atlanta has also had significant oil carryover problems with its Gemini compressor (also of unknown model and flow rate to the person surveyed).<sup>22</sup> These examples illustrate another point that is discussed below: users of CNG systems – even maintenance personnel responsible for their upkeep – can be unfamiliar with the detailed features of their equipment. This phenomenon contributes to the barriers faced by expansion of the CNG fueling infrastructure.

ARCADIS Geraghty & Miller e-mailed a series of questions to Gemini about its strategy to control oil carryover, including an inquiry if Gemini is moving towards a non-lubricated compressor design. The company is “not aware of any oil carryover issues” with its compressors, but requested greater details about which sites have had problems, including the name of the system packagers (further emphasizing a key point in Section 2.3). Gemini reportedly minimizes oil carryover in its compressors by “setting the lubricator to the minimum oil flow to the cylinders” and using coalescing filters, but does not require the use of synthetic oil.<sup>23</sup>

Hurricane compressors address the problem of oil carryover through the use of cooling technologies combined with a “Delivery Gas Hydrocarbon Adsorber.” Hurricane claims this removes 100% of oil aerosols and vapors” in the compressed gas without “the high maintenance cost associated with ‘oil-less’ compressors.”<sup>24</sup> According to the Institute of Gas Technologies, use of this type of adsorption technology is in its initial phase, and more information is needed about life-cycle costs.<sup>25</sup> Hurricane offers a unique "MonoBlock" design on several compressor models in which the same natural gas engine is used for power and gas compression. This is accomplished by reconfiguring Ford V8 engines so that the four left cylinders are used for power and the four right cylinders are used for gas compression. ARCADIS Geraghty & Miller received insufficient feedback from Hurricane users to comment on the effectiveness of its oil-control technology, or the durability and reliability of Hurricane compressors in general.

For most applications involving CNG stations of mainstream size (200 to 300 scfm), the best oil-control solution appears to be the use of well-engineered lubricated compressors such as those made by Ariel or Sulzer in tandem with synthetic oil and coalescing filters. Trillium USA has had success using Ariel compressors with synthetic oil and 6 stages of coalescing filters (inlet, each stage of compression, outlet), and will use such a system in two new CNG installations at LACMTA. As noted above, the synthetic oil costs about five times more than mineral oil, but is worth the extra cost due to its increased life and effectiveness at reducing oil carryover.<sup>26</sup>

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<sup>21</sup> Larry Richards, OmniTrans, personal communication to Jon Leonard.

<sup>22</sup> Terry Walker, Checker Cab Company, personal communication to Jon Leonard.

<sup>23</sup> Jeremy Rowand, Gemini Compressors, e-mail to Jon Leonard.

<sup>24</sup> Hurricane product literature.

<sup>25</sup> GRI Final Report GRI-97/0398, *NGV Fueling Station and Dispenser Control Systems*.

<sup>26</sup> Don Donaldson, Trillium USA, personal communication to Jon Leonard.

Non-Lubricated Compressors - An alternative oil mitigation strategy is the use of “non-lubricated” compressors, which aren’t truly oil free, but use lubricating methods that minimize the amount of oil getting into the compression chamber. These compressors use non-metallic piston rings, which are less abrasive and provide a measure of lubricity. Non-lubricated compressors generally cost more than lubricated types because they require additional engineering, such as the use of liquid cooling and/or slower engine speeds. Also, non-lubricated compressors can entail higher maintenance costs due to the need for more frequent rebuilding. Current experience indicates that at least one brand of non-lubricated compressor has achieved 3,000 to 4,000 hours of ring life under actual operating conditions, equivalent to approximately one year of service. It is expected that improved ring materials will further increase this interval, although the time between rebuilds for the best-quality lubricated compressors is still about three times longer. Further documentation of the durability of non-lubricated compressors of various designs is needed to compare maintenance intervals and costs.

The higher costs associated with non-lubricated compressors may be offset by a number of potential advantages. For example, non-lubricated compressors lessen or eliminate the need to maintain coalescing filter systems, and – because they have no oil sump requiring periodic draining – offer less disposal issues. These can be important benefits for users that don’t have their own vehicle maintenance facilities or routinely dispose of hazardous fluids.

IMW Atlas is one of the leaders in non-lubricated compressor technology for medium to large flow capacities. IMW Atlas uses a crosshead cylinder design manufactured specifically for natural gas compression, which they claim results in “virtually no carryover of oil or contaminants to the consumer.” IMW Atlas cylinders use specially hardened Teflon piston rings and packing, “frictionless” valves designed especially for non-lubricated compressors, and extremely close-tolerance finishes inside cylinders. IMW Atlas says that their liquid-cooled, low-RPM compressors run slower and cooler than most others, resulting in a “typical ring life” of “4,000-6,000 hours,” or about “triple that of most competitors.”<sup>27</sup> Surveyed users of IMW Atlas compressors generally recommend this brand of compressors (see Appendix A).

Dresser Rand, which recently entered into an exclusive teaming agreement with IMW Atlas, manufactures two non-lubricated compressor models that have worked well in lower-flow capacities (28 and 56 scfm). Dresser Rand’s agreement with IMW Atlas should further strengthen its non-lubricated compressor technology. FuelMaker has carved out a similar niche in small non-lubricated compressors, although they are limited to low-suction pressure applications. With the help of GRI, FuelMaker has improved the reliability and heat transfer of its “totally oil-free” Quantum compressors and can now provide 3,000 hours of ring life.<sup>28</sup> Note that this is half the upper limit for the “typical” ring life claimed by IMW Atlas. FuelMaker has taken a different engineering approach by putting less expense into long ring life while making it easier and cheaper to replace worn-out rings. FuelMaker compressors are equipped with a drop in and out head

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<sup>27</sup> IMW Atlas product literature.

<sup>28</sup> Bill Liss, GRI, personal communication to Jon Leonard.

assembly, which allows rings to be changed every 3,000 hours by a simple, two-hour process at the cost of \$200 to \$300. Even simpler, FuelMaker now swaps out the entire compressor unit (unscrewing a total of four bolts) for its customers after 3,000 hours.<sup>29</sup> Rix non-lubricated compressors are also designed for an easy change-out of piston rings at the site.

Non-lubricated compressors are a relatively new development for the CNG industry that may challenge the use of lubricated compressors for increasing market share. Additional durability data may be needed to accurately assess life-cycle costs of non-lubricated compressors, especially for the larger machines used in fast-fill applications. Some industry experts have questioned the ability of such machines to achieve their claimed ring life in real-world use, and suggest that such models may result in higher maintenance costs than the user expects.<sup>30</sup>

Given that experience with non-lubricated compressors is more limited than lubricated models, and some industry people remain skeptical about their use in mainstream fast-fill applications, it is prudent for potential users to carefully select such a system and require detailed, real-world durability data.

Effectiveness of On-Vehicle Filters - Most manufacturers of natural gas engines, vehicles and fuel systems require their customers to use CNG that adheres to SAE and/or ARB guidelines on oil carryover. In reality, however, levels of oil carryover in CNG often exceed these guidelines, and certain CNG fuel systems are especially susceptible to adverse effects. While the problem of oil carryover appears to be gradually improving with better CNG station technology, automotive engineers have taken steps to mitigate the problem on-board the vehicle.

For example, Cummins is concerned about this problem affecting electronic valves and mass flow sensors in its natural gas engines such as the L-10G and the C8.3G. The Cummins flow sensor is designed to measure gaseous fuel flow using a hot-wire anemometer device. Cummins does not know how much oil in the fuel is deleterious for its proper operation, but excessive amounts definitely cause problems. Sticking and deterioration of seals for electronic fuel shutoff and control valves can also occur. To reduce oil carryover, Cummins supplies a low-pressure (50-150 psig) coalescing filter with its CNG engines, which removes contaminants greater than 1 micron, including water and oil.<sup>31</sup>

Impco Technologies also engineers its CNG fuel systems to mitigate oil carryover on the vehicle. Since CNG customers are unlikely to know about the oil content of CNG at a given station, it is up to the vehicle/fuel system manufacturers to deal with the problem without unnecessarily alarming vehicle users. Impco designs its CNG systems with vapor delivery that is tolerant to oil carryover. Like Cummins, Impco uses a coalescing 1-micron filter that drains to a sump. However, the filters are located downstream of the tanks because low-pressure inlet filters have not proven practical to Impco. This system works well on oil carryover in liquid form but may not

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<sup>29</sup> Paula Hebert, FuelMaker Corporation, personal communication to Jon Leonard.

<sup>30</sup> Based on input from GRI's Bill Liss and Trillium USA's report on oil carryover.

<sup>31</sup> Jim Branner, Cummins Engine Company, personal communication to Jon Leonard.

be effective on vaporized oil. The filter sump must be drained at about the same frequency of an oil change, depending on the amount of oil carryover that has collected.<sup>32</sup>

BayTech Corporation, which makes and markets NGV fuel-injection systems, also addresses oil carryover through the use of on-vehicle filters. BayTech was involved in a project in Atlanta where a CNG compressor was producing so much oil carryover that the vehicles' storage tanks accumulated gallons of oil. The subsequent retrofit of coalescing filters on the vehicles resolved the problem. BayTech now puts a high-pressure coalescing filter on every NGV kit it sells, and the result has been a significant improvement with injector and system reliability.<sup>33</sup>

It is important to note that some oil carryover is essential for most CNG fuel injection systems. CNG station specifications requiring oil carryover that is too low (some have reportedly specified parts per billion) may not allow for proper lubrication of NGV fuel management systems. Ford recently put out an advisory stating that use of CNG with no oil (such as the case in "L/CNG" produced from LNG) can void the warranty for Ford CNG vehicles. Oil carryover – too much or too little -- is a concern at Ford's AFV Department. Ford uses a Bosch injection system that is recommended for a minimum of 70 ppm but not more than 200 ppm of oil carryover. Ford equips its CNG vehicles with coalescing filters that have been marginally effective, but fortunately the Bosch system can tolerate more than 200 ppm.<sup>34</sup> Other CNG fuel systems such as the GFI bi-fuel system can have significant difficulties at less than 200 ppm of oil carryover.<sup>35</sup> Unfortunately, there is no easy, accurate way for an NGV user to measure oil carryover in the field.

Honda's CNG injection system is designed for relatively dry fuel, and its regulators can be susceptible to fuel contaminants. It is unclear if Honda is using a coalescing filter on the CNG-fueled Civic, but oil carryover has not been a problem, according to a Honda representative. Honda has established a program whereby FuelMaker's non-lubricated compressors are the preferred refueling system for CNG Civics, which may in part explain the apparent lack of an oil contamination problem. Honda engineers have attempted to maximize range on the CNG Civic, so they have made it a goal to avoid reductions in the usable tank volume due to oil contamination. Honda has not established any correlation between emissions from its NGVs and oil carryover levels, but it was noted that there isn't much margin for emission control system problems at SULEV levels.<sup>36</sup>

## 2.4.2 Moisture Content and Dryer Systems

Natural gas distributed in the US and Canadian piping networks contains water vapor. SAE Standard J1616 specifies that pipeline quality natural gas can contain up to 7 lbs or more of water

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<sup>32</sup> Bruce Johnson, Impco Technologies, personal communication to Jon Leonard.

<sup>33</sup> Rebecca Royer, BayTech Corporation, personal communication to Jon Leonard.

<sup>34</sup> Tom Barker, Ford AFV Department, personal communication to Jon Leonard.

<sup>35</sup> Tom Barker at Ford, corroborated by GFI's Notes provided to Natural Gas Fueling Station Technology Exchange VII, September 1996 in Park City, Utah.

<sup>36</sup> Ben Knight, Honda R&D, personal communication to Jon Leonard.

per million standard cubic feet (MMSCF) of gas. About 60% of California's natural gas comes from Canada with a typical moisture content of 2 lbs./MMSCF. California well gas has greater quantities of moisture but does not exceed 7 lbs./MMSCF, according to various gas utilities. However, it is common for gas to exceed the SAE J1616 specification, and in extreme cases moisture can be an order of magnitude higher. For example, the moisture content of pipeline gas can be high during winter months, when gas is withdrawn from relatively wet storage wells. In the summer, local gas suppliers (not necessarily in California) sometimes shut off their gas dryers to save maintenance and power costs, leading to spikes of moisture as high as 100 lbs./MMSCF.<sup>37</sup>

Gas-drying equipment at CNG stations can be expensive and maintenance intensive. The type of dryer that is employed is in part determined by the site's suction pressure. Suction pressure exceeding 20 psi allows the installer to use a suction side dryer. Lower suction pressures may require the dryer to be located on the high-pressure, discharge side. High-pressure twin tower dryers have been particularly troublesome for some CNG stations operators, especially those with a large gas throughput, like the transit districts. This is discussed further below.

Packagers/installers that can get by without installing dryers usually do so. Southwest Gas in Arizona doesn't use dryers because local gas is relatively dry, and existing moisture is readily removed by the multiple stages of compression and cooling in a typical CNG compressor. In this situation, because dryers have very high operation and maintenance (O&M) costs, their use may not be justified at stations with low CNG throughput. Southwest Gas therefore performs a careful analysis to determine the benefits and drawbacks of installing a gas dryer system.<sup>38</sup> Fleetstar has removed the gas dryer system at its Oxnard station.<sup>39</sup> Pickens Fuel Corporation was able to build its new Waste Management CNG fueling station in Palm Desert without a gas dryer because the station's natural gas source does not include well gas.<sup>40</sup> These are examples of how CNG fueling stations have unique parameters, which, if carefully assessed, can allow the station installer/operator to save significant capital and O&M costs.

However, some industry insiders caution that all California CNG station installations should be equipped with gas-drying capabilities.<sup>41</sup> Like many organizations, Southern California Gas favors gas dryers made by Xebec, which work very well as suction side (low-pressure) gas dryers in typical California conditions, or those made by Pneumatic Products. Unfortunately, maintenance and regeneration of gas dryers can be labor intensive processes that lead to higher costs and station downtime. Also, hazardous waste from gas dryers adds to the operating cost of a CNG station.<sup>42</sup>

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<sup>37</sup> Information in this paragraph provided by several people in the gas utility and CNG fueling station industries.

<sup>38</sup> Mark Haught, Southwest Gas Company, personal communication to Jon Leonard.

<sup>39</sup> Greg Dahl, FleetStar, personal communication to Jon Leonard.

<sup>40</sup> Jim Harger, Pickens Fuel Corporation, personal communication to Jon Leonard.

<sup>41</sup> Ron Smith, (formerly of) Southern California Gas, personal communication to Jon Leonard.

<sup>42</sup> Stan Sinclair, Southern California Gas, personal communication to Jon Leonard.

ARCADIS Geraghty & Miller surveyed many CNG station users by telephone to determine if gas moisture has been a problem for their CNG vehicles or fueling station equipment. Many users were not well informed about the issue; some did not know if their system included a dryer. The exception tended to be transit districts, which have high gas throughput and typically employ regenerative dryers. For example, SCAT in Oxnard uses a twin tower automatic regenerating model 750 from Pneumatic Products. SCAT has not had any major problems, probably in part because they use a contractor to maintain the system. However, the disposal of the hazardous effluent is a significant issue. SCAT analyzed the water and found concentrated methyl mercaptans with trace amounts of other toxics. During maintenance and disposal, they must be careful not to vaporize the waste material, because it represents a potential health and safety issue with employees.<sup>43</sup>

For its existing CNG stations, LACMTA has used in-house service personnel to operate and maintain its twin tower auto regenerative dryers. After experiencing significant problems, service personnel decided to bypass the dryer systems. As a result, LACMTA's CNG buses sometimes ice up during fueling, but this phenomenon has not significantly impacted operation of the buses.

The problems that LACMTA experienced with its dryer systems were partly attributable to a lack of knowledge of dryer systems on the part of its service personnel.<sup>44</sup> Recently, LACMTA executed a 10-year capital lease agreement whereby Trillium USA will build, own and maintain new CNG fueling stations at Divisions 5 and 7 under LACMTA's Public/Private Partnership Program. These stations will include high-pressure dryer systems, for which Trillium USA will be totally responsible for maintaining (using LACMTA's unionized labor). As discussed further below, both Trillium USA and LACMTA expect this arrangement to improve the reliability and performance of gas-drying systems at these two new stations, compared to LACMTA's existing CNG stations.

ARCADIS Geraghty & Miller also discussed the issue of gas moisture with individuals on the vehicle and fuel system manufacturing side of the CNG industry. In general, it is not uncommon for NGVs to experience some freezing of regulators and injectors due to moisture. BayTech Corporation found that icing problems on its gaseous fuel injection system subsequently disappeared when certification quality CNG was used instead of pipeline gas.<sup>45</sup> Even when the gas is dry, ambient air moisture can lead to nozzle icing in certain climates; for this reason, the Ford CNG fuel system is designed to minimize pressure drop at the check valve, where it is most important to avoid icing. However, this has not been a major problem for Ford.<sup>46</sup> In general, surveyed users and industry insiders indicated that gas moisture problems are not a significant impediment to expansion of NGV use. At the time this report was being written, nozzle manufacturers such as Sherex were reportedly working on new designs to overcome icing problems.

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<sup>43</sup> Peter Drake, SCAT, personal communication to Jon Leonard.

<sup>44</sup> Warren Fu, LACMTA, personal communication to Jon Leonard.

<sup>45</sup> Rebecca Royer, personal communication to Jon Leonard.

<sup>46</sup> Tom Barker, personal communication to Jon Leonard.

### 2.4.3 Non-Methane Content

In certain areas of California, CNG contains greater percentages of higher hydrocarbons than specified by ARB. According to the ARB, these areas are in the South Central Coast and in certain parts of the San Joaquin Valley where CNG is produced in association with oil production. CNG produced in these areas marginally exceeds the ethane specification (usually in summer) and may exceed other specifications. However, fuel blending is used to comply with ARB specifications, and test data indicate that virtually all types of on-road vehicles can operate on CNG fuel with ethane amounts outside the specification tolerances. Additional emission test data are needed to determine the emissions implications of ethane in CNG fuel.

In some areas high levels of propane in natural gas can arise from propane-air peakshaving activities. High propane levels can lead to propane condensation in CNG compressors that can cause damage because the liquid cannot be compressed. Vehicles can also be adversely affected. However, in conjunction with GRI, IGT performed a comprehensive survey of gas utilities nationwide and concluded that “for the NGV market, propane-air peakshaving represents a diminishing concern.”<sup>47</sup> This was confirmed by several industry insiders as well.

## 2.5 FUEL PRICE

An important driver for the NGV market is the cost advantage of natural gas over gasoline or diesel, although this advantage is diminished during periods of extremely cheap petroleum prices. The price of CNG, which has been fairly stable in the 1990s, depends on many complex factors. Some of these are addressed below and throughout this report, but a comprehensive discussion is beyond the scope of this study. An overview of pricing structures is provided.

Natural gas is measured by volume or weight (standard cubic feet or pounds), but is sold by energy content (therms, or 100,000 Btu).. In 1998, the delivered price of uncompressed, processed gas to commercial and industrial users ranged from 30 to 55 cents per therm (38 to 69 cents per GGE<sup>48</sup>) depending on the volume purchased and other factors.<sup>49</sup> The cost of on-site gas compression can add anywhere from 10 cents to 22 cents per therm (12.5 to 27.5 cents per GGE).<sup>50</sup> The cost of operation and maintenance for a CNG station can add another 10 to 30 cents per therm (12.5 to 37.5 cents per GGE). If the station operator wants to have an open access station with a card reader system, he must add the collective expense of capital equipment, data management, bill processing, and charges for the service. Next, the station and/or fuel provider

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<sup>47</sup> GRI Final Report GRI-96/0201, *Propane-Air Peakshaving Impact on Natural Gas Vehicles*.

<sup>48</sup> Using 125 scf per GGE.

<sup>49</sup> Energy Information Administration/Natural Gas Monthly April 1999, *Natural Gas 1998: A Preliminary Survey*.

<sup>50</sup> The cost of compression can vary widely depending on the type of prime mover and the required horsepower to compress the gas. This latter parameter is mostly a function of site suction pressure, which dictates the number of stages of compression (capital cost) and the amount of work required. According to John Veranicar of PG&E, for an electric motor-driven compressor it requires a little more than twice as much power to compress a therm of gas at a suction pressure of 5 psi as it does at 300 psi.



must add his cost of doing business. Finally, with the exception of fuel used by government fleets, taxes are added to the fuel cost.

Gas utilities each set the price of natural gas according to unique tariffs and pricing structures. This can result in a wide range of pricing for CNG compared to gasoline. The price of CNG at GRI's "cost-effective" stations (as of early 1999) ranged from \$0.65 to \$0.98 per GGE (see Table 1 in next section). According to its website, San Diego Gas & Electric charges as much as \$1.40 per GGE (no detail is given). PG&E sells CNG at its fueling stations for \$0.78104 per therm (plus a monthly customer charge of \$13.42 per account - no vehicle limit).<sup>51</sup> This equates to \$0.86 per GGE. The Long Beach Gas & Electric Department (LBG&E) currently sells CNG for an estimated average per-therm price of \$0.79<sup>52</sup>, or about \$0.87 per GGE. LBG&E purchases natural gas for its customers on the monthly Spot Market, and publishes a rate list entitled "Schedule 5 – Compressed Natural Gas". LBG&E charges different prices for customers according to whether or not the compression is performed by the customer or by LBG&E. The final charge to the customer can be adjusted for applicable taxes and a "commodity charge" of up to 10% to "reflect current changes in market conditions."<sup>53</sup>

Private-sector CNG fuel providers such as Pinnacle, Trillium USA and FleetStar use their own pricing structures, but the most important determinant is station throughput. Although the per-gallon margin can be greater on CNG than petroleum fuels, the sales of gasoline at a typical station can be five or more times that of CNG on an equivalent basis. These companies derive a fuel price by starting with their raw gas cost in dollars per therm, and adding the costs of compression and O&M. In many cases, the station owner/operator has fixed O&M costs because maintenance cycles are based on time, not operating hours. Thus, low throughput does not necessarily mean reduced O&M costs. The station owner must sell a minimum volume of fuel to recover costs and make a return on investment. The final price of CNG for these types of stations is a function of the fuel volume pumped and whatever the market will bear after the costs of compression, O&M, and profit are added.

Accordingly, many turnkey companies now offer "take or pay" pricing arrangements to station users, in exchange for providing complete station design, equipment purchase, integration and installation, code compliance, operational and maintenance support, and even assistance in procuring government funding. For example, Southwest Gas in Arizona has a contract to purchase CNG from Trillium USA for stations in Phoenix that include both public and private access. Under its agreement with Trillium USA, Southwest is required to purchase 45,000 GGE per month for that station, and over the next few years the minimum volume will increase. Trillium USA charges Southwest Gas about \$0.99 per GGE, and Southwest Gas is able to add a few cents

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<sup>51</sup> This is a simplified version: PG&E's pricing system involves "GNGV-1" and "GNGV-2" rates that are derived by the type of customer and numerous other variables.

<sup>52</sup> Ginger Shugart, Long Beach Gas & Electric Department, e-mail to Jon Leonard.

<sup>53</sup> LBG&E website.

per GGE to the price of CNG it sells on the public-access side of the station.<sup>54</sup> Pickens Fuel Corporation and Pinnacle are other turnkey companies aggressively marketing such agreements to station users who are willing to buy a specific volume of fuel over a specific period of time. Pinnacle charges between \$1.00 and \$1.10 per GGE for dispensed CNG at its high-throughput California CNG stations, such as the UPS facility in San Ramon. Such agreements appear to offer cost-effective fuel purchase options for fleets that use large volumes of fuel<sup>55</sup> each year. This is discussed further in the section on Station Life-Cycle Costs.

On average, the retail price of CNG in California was approximately \$1.00 per GGE as of May 1999. The Alternative Fuel Promotion Act that was recently introduced to Congress by Senator John Rockefeller will create a \$0.50 per GGE tax credit to sellers of alternative fuels to make them more competitively priced with traditional fuels. If passed in its current form, this legislation will significantly reduce the price of CNG by approximately 50% and provide significant new incentive for fleets to purchase NGVs.

ARCADIS Geraghty & Miller's informal survey of CNG station users indicated that many are unsure of what price they pay for CNG, especially those who purchase raw gas and must calculate the complex costs of compression and O&M. Executives at turnkey fuel and infrastructure companies tend to stress that only the market can decide the price of CNG fuel, and prefer that government agencies focus on helping fleets obtain reliable compressed fuel at the lowest price. They believe that the CNG station and fuel market in California is a private entrepreneurial market that will install new public refueling stations only as profit motives respond to demand.

## 2.6 STATION LIFE-CYCLE COSTS

According to a recent GRI/AGA document,<sup>56</sup> the installed costs for public-access CNG stations of 100 to 300 scfm capacity have historically ranged from \$1,400 to \$2,000 per scfm.<sup>57</sup> A relatively short-term target of the NGV industry is to reduce this cost below \$1,000 per scfm. As previously discussed, one important way to achieve this is to minimize the amount of customization. In general, however, there is no clear blueprint for builders of CNG fueling stations to achieve the \$1,000 per scfm cost objective. In the above-noted document, Corliss and Associates prepared an assessment for GRI and AGA of "cost-effective" existing CNG fueling stations in North America ranging in cost from \$568 to \$1,121 per scfm. A summary of these stations is provided in Table 1. The six companies portrayed in the study successfully devised and implemented their own approaches to reducing the costs of NGV fueling stations. While the study provides useful insights into cost-reduction methods, it should be noted that each of the six profiled companies is a gas company or energy company, and cost-reducing measures they employed may not be available to the turnkey fuel companies that hope to build CNG stations for profit.

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<sup>54</sup> Ed Hempelman, Southwest Gas Company, personal communication to Jon Leonard.

<sup>55</sup> Pinnacle seeks a fuel demand from each station of approximately 165,000 GGE per year within three years of start-up on a 10-year contract, according to its website (<http://www.pinnaclecng.com>).

<sup>56</sup> Gas Research Institute, *Case Studies of Cost-Effective Natural Gas Fueling Stations*.

<sup>57</sup> The parameters and assumptions used to calculate a station's cost in \$/scfm appear to be poorly defined.

The Alternative Fuel Promotion Act, which was recently introduced in Congress by Senator John Rockefeller, will expand the current tax deduction for alternative fueling capitol equipment to include the cost of installation. This provision would create a \$30,000 tax deduction for the installation of an alternative fueling station, and should provide additional incentive for fleets to purchase NGVs.

Beyond the issue of high capital costs, O&M costs must also be significantly reduced to lower the life-cycle costs of CNG stations. Virtually all station components require preventative maintenance on a regular basis to maintain station reliability. The compressor system is the single most critical component, but other equipment such as dryers, dispensers, tubing and panels also require regular inspection and maintenance. The frequency and type of maintenance for a given station depends on many factors, especially site parameters like suction pressure that largely dictate the type of equipment that was originally installed. Depending on how much maintenance is typically needed and the degree of in-house expertise, the station operator must either pay on-site staff to perform the maintenance, or pay for a contractor's services.

Table 1. GRI's Examples of "Cost-Effective" CNG Stations

Station Parameter	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Operator / User	Columbia Gas	Consumers' Gas Co.	Southern Union Econofuel Co.	Lone Star Energy	Total Petroleum	Union Gas Ltd.
Location	Columbus, OH	Scarborough, Canada	Austin, TX	Dallas, TX	Denver, CO	Chatham, Ontario
Packaged by	Krause	Consumers' Gas Co.	Southern Union Econofuel Co.	FleetStar	Natural Fuels Corporation	Union Gas Ltd.
Application	Public mix	Public mix	Public, mostly MDVs HDVs	Public mix	Public mix	Public mix
Compressor Brand	Ariel	Sulzer	Gemini	Gemini	Ariel	NA
Prime mover	95 hp Caterpillar 3304	100 hp electric motor	145 hp gas engine	Caterpillar 3306 engine	100 hp electric motor	100 hp electric motor
Dispenser Type	Krause	Unknown (custom built)	DVCO / Marcum Fuel Systems	Clean Fuels Technologies	Natural Fuels	NA
No. of Dispensers / Hoses	1 / 2	3 / 6	1 / 2	2 / 4	1 / 2	1 / 2
Rated Flow (cfm)	267	250	227	614	224	200-250
Suction pressure (psig)	45	155	20	350	20	40-60
Discharge pressure (psig)	5000	3600	4500	4000	4700	3600
Service pressure (psig)	5000	3000	3000	3000	3000 or 6000	3000
Storage capacity (scf)	39,000	30,000	> 25,000	35,000	40,000	20,000
Card-Key system	E.J. Ward	Unknown	Credit card system	FleetStar system AutoGas	Tech 21	Unknown
Peak Vehicle Service	50 vehicles / hour	40 vehicles / hour	NA	NA	30 vehicles / hour	15 vehicles / hour
Average Vehicle Service	200 vehicles / day	260 vehicles / day	NA	NA	NA	250 vehicles / day
Claimed Fill Time from Dispenser (~8 GGE)	2 minutes	3 minutes	4.8 minutes	3 minutes	2-3 minutes	5.5 minutes
Fuel Price (GGE)	\$0.65	NA	\$0.66	\$0.80	\$0.81	\$0.98
Cost per scfm	\$816	\$1,121	\$972	\$568	\$1,074	\$1,115

The dilemma of how to properly maintain a CNG station can pose difficult problems for certain fleets. Many public-sector operators simply don't have the appointed people to maintain a complex fueling station. Even large transit districts with full-time maintenance staffs have had difficulty keeping system components like gas dryers and engine prime movers operational

(discussed more below). Service and maintenance contracts are often desired but it can be difficult for station operators to find reputable companies offering affordable agreements. The end result is that many CNG stations do not get the necessary maintenance to operate reliably and at reasonably low O&M costs.

This is the major reason why fleets with very large throughputs of CNG fuel are increasingly executing agreements with the turnkey companies to purchase prescribed volumes of fuel for all-inclusive service and operating contracts. For example, LACMTA recently executed a 10-year capital lease agreement whereby Trillium USA will build, own and maintain new CNG fueling stations at Divisions 5 and 7 under LACMTA's Public/Private Partnership Program. After ten years LACMTA will reportedly purchase the Trillium USA CNG facilities for \$1. The cost for the Trillium USA lease is composed of fixed monthly charges over ten years, covering the facilities investment and other costs, plus a small recurring charge per therm of gas consumed, which will be all inclusive for compression energy and maintenance. These are fixed-price commitments (inflation included) that provide LACMTA with pinpointed costs for the new CNG stations over the next decade. Moreover, the agreement includes a guarantee by Trillium USA that there will be no cost overruns on the construction of the two CNG fueling facilities, and penalties to Trillium USA for non performance when buses are not able to get CNG fuel.<sup>58</sup> For a 200-bus CNG fueling station, ARCADIS Geraghty & Miller estimates that this type of contract offers a 15% cost savings over ten years compared to LACMTA purchasing and operating its own CNG stations.

The new Trillium USA capital lease agreement with LACMTA is the first of its kind for a transit district in California. While these types of agreements may represent the future of the CNG fueling station industry, currently they are available only to fleets that can guarantee high volumes of gas throughput. To meet a minimum-targeted consumption of 14,000 GGE per month, a typical package-delivery fleet would need to operate 23 medium-duty CNG vehicles about 100 miles per day, 30 days per month. The many fleets with lower fuel consumption who already own and operate CNG fueling facilities (or are considering such an investment) are faced with important decisions about how keep life-cycle costs as low as possible. ARCADIS Geraghty & Miller solicited input from station users and knowledgeable industry representatives about key issues towards this end. The following summarizes our findings.

### 2.6.1 Compressor Prime Movers: Electric Motors Versus Gas Engines

A fundamental choice for CNG fueling stations is whether to use an electric motor or an internal combustion engine as the prime mover to power gas compression. Both options offer certain advantages and disadvantages, depending on the intended application and other factors. Electric motors are relatively inexpensive, have minimal environmental siting issues, don't require extensive maintenance, and are extremely reliable. Their main disadvantage is that compression costs can be very high if the motors are operated during peak hours and/or in areas with expensive electricity. They are also subject to power blackouts. By comparison, natural gas engines provide relatively

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<sup>58</sup> Jan Hull, Trillium USA, personal communication to Jon Leonard and Rich Remillard.

inexpensive power in terms of fuel costs, and they are independent of the electricity grid in the event of a power outage. However, they are labor intensive, have higher maintenance costs, are not as reliable as electric motors, and can have significant costs associated with environmental issues (emissions and noise).

Most packager/installers offer CNG compressor packages with either type of prime mover, and will make a recommendation based on site specifics and customer preferences. ARCADIS Geraghty & Miller telephone-surveyed more than 40 CNG station users about the type of prime mover utilized at their station. Most users knew the type of prime mover (electric motor or engine) but not the specifics such as brand and horsepower rating. As a general rule, small- to medium-sized CNG stations utilize electric motors, avoiding the higher capital and maintenance costs of a gas engine drive. These stations tend to have relatively low throughput, requiring intermittent service of compressors – a duty cycle that favors electric motors. For larger systems with high gas throughput, especially transit districts that have trained on-site maintenance personnel, the relatively high cost of electricity for gas compression may make gas engine drive more attractive. In addition, transit districts prefer to be able to operate buses independent of the electricity grid in the event of power failures.

However, choosing an engine drive prime mover over an electric motor drive can have major implications to the life-cycle costs of a CNG station. First, engine-driven compressors generally require more system redundancy than electric-driven compressors because engines fail more frequently than electric motors (although some customers may desire engine backup for motor-driven systems in the event of power failures). Second, engines have higher maintenance costs, and require “extreme attention to detail,” according to transit district maintenance supervisors who use them. Third, a major downside of gas engine prime movers can be the expense, time and difficulties associated with obtaining air quality permits. The initial permit is not prohibitively expensive – about \$1,700 depending on the air district in which the station is located. However, additional costs can apply. For example, SCAT in Oxnard is required to perform an annual independent emissions test on the two Caterpillar G3408TA engines that power its Gemini compressors, which costs about \$3,600. To self monitor emissions, SCAT purchased a refurbished emissions analyzer for about \$10,000. When an engine exceeds NOx limits a temporary permit must be acquired for \$500. Any change in the permit costs \$1,000.<sup>59</sup>

SCAT’s CNG station was installed in 1995, and since then control-logic and emissions problems have occurred with the Caterpillar engines. NOx levels were frequently out of compliance with the Ventura County Air Pollution Control District’s regulations, severely limiting operating time.<sup>60</sup> In mid 1998, SCAT sought assistance from the Caterpillar factory or local dealer, and eventually Hawthorne Power Systems was brought in to help. The engineer performing the analysis indicated that the SCAT CNG station was “a poor application for an emissions controlled ICE” because the

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<sup>59</sup> Peter Drake, personal communication to Jon Leonard.

<sup>60</sup> Ibid.

catalytic converter could not reach light-off temperature. The technician concluded that the SCAT CNG station “would be best served by an electric motor drive . . .”<sup>61</sup>

SCAT had already made significant investments in its Caterpillar engines, so Hawthorne Power Systems recommended that both engines receive an upgrade for better electronic controls. The upgrade was expensive (\$90,000 per engine) but has apparently solved the major problems. SCAT general manager Peter Drake offers this advice for those who chose to purchase an engine drive system: “Make sure you get the latest electronic controls when you buy the system.”<sup>62</sup>

Other California transit properties have also faced difficult choices and problems related to the choice of prime mover type. OmniTrans of San Bernardino County has had major problems with two Caterpillar engines at its Montclair facility since they were first installed in 1994. High NOx emissions have severely restricted the engines’ operating hours, even though the catalytic converters have been replaced multiple times.<sup>63</sup> Noise can also be a significant issue for large engine-drive prime movers. The SCAT CNG station is located in a residential area, making it necessary to use noise enclosures around the Caterpillar G3408TA engines. This arrangement leads to heat-dissipation problems that demand greater time and money. Careful consideration of all the environmental factors should be addressed before siting CNG stations in residential areas. (See Section 2.8)

Primarily as the result of problems described above, at least one of the major turnkey companies will no longer install engine-drive systems.<sup>64</sup> On the other hand, Trillium USA plans to utilize Caterpillar natural gas engines for prime movers at the two new stations it will install and operate at LACMTA. Trillium USA engineers believe that application of a rigorous, “calendar-type” maintenance regime under its own on-site supervision (part of the comprehensive service agreement) will make engine drive significantly less costly than electric drive on a life-cycle basis. They are confident that there will not be problems with control logic of the engines or complying with air quality regulations.<sup>65</sup> These will be the first engine prime movers at LACMTA -- all of its existing CNG compressor stations are powered by electric motors. This has enabled LACTMA staff to avoid major maintenance and air quality permitting problems, but electricity costs require them to operate compressor stations during off-peak hours whenever possible.<sup>66</sup>

Operational characteristics and life-cycle costs of the engine-drive systems to be installed at LACMTA Divisions 7 and 9 will be determined over the next several years. Based on currently available information, it appears that electric drive is the most cost-effective prime mover choice for most mainstream CNG fueling stations. Engine-drive systems have potential to be more cost-

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<sup>61</sup> Hawthorne Power Systems, *CAT Service Engineer Technical Report*.

<sup>62</sup> Peter Drake, personal communication to Jon Leonard.

<sup>63</sup> Larry Richards, OmniTrans, personal communication to Jon Leonard. (Mr. Richards did not know the model number of the Caterpillar engines used at OmniTrans.)

<sup>64</sup> According to an industry executive who asked to remain anonymous.

<sup>65</sup> Jan Hull, Trillium USA, personal communication to Jon Leonard and Rich Remillard.

<sup>66</sup> Warren Fu, personal communication to Jon Leonard.

effective at high-throughput facilities where electricity costs are exceptionally high, but a comprehensive turnkey company agreement is recommended for the host fleet, like the one between LACMTA and Trillium USA. From an environmental standpoint, public regulatory agencies probably should focus on funding installations that use electric drive, due to their lower level of life-cycle emissions and reduced noise impact.

Regardless of the type of prime mover that is used, proper alignment between the prime mover and compressor is important to avoid a high rate of bearing wear. This is an especially critical issue at large transit stations, where vibration of the prime mover can result in poor alignment. PG&E uses laser technology to align both gas and electric drive systems. The laser tool costs \$14,000, which may be cost prohibitive for the typical NGV station user.<sup>67</sup> However, other options exist to ensure good alignment that may be equally effective at lower cost. SCAT and LACMTA periodically hire outside vendors to perform this service.<sup>68</sup> For the two new stations planned at LACMTA, Trillium USA claims that laser alignments won't be necessary because vibration will be controlled through improved foundation engineering and precise initial alignment.<sup>69</sup> For future installations, compressor manufacturers such as Sulzer are reportedly working on new systems that will have reduced bearing wear and significantly lower maintenance costs.

## 2.6.2 CNG from LNG Stored On-Site (L/CNG)

A possible alternative source of CNG for fleets is to build (or obtain access to) a fueling station where CNG is dispensed from LNG that is stored on site. This is accomplished by using high-pressure cryogenic pumps to compress the LNG to 4,000–4,500 psi and then vaporizing the highly compressed liquid. CNG derived from this “L/CNG” process offers several advantages over conventional CNG. First, cryogenic pumps require significantly less energy than the compressors used at conventional CNG stations, and are less maintenance intensive. Second, L/CNG is delivered to the NGV at ambient temperature, facilitating complete fills while obviating the need for temperature compensation systems. In addition, since LNG itself is essentially pure methane, L/CNG is delivered to the vehicle with virtually no contaminants or undesirable fuel elements such as oil carryover, moisture, and higher hydrocarbons. This eliminates the need for elaborate gas drying and filtering systems.<sup>70</sup>

The ALT-USA/FleetStar station on UPS property in Ontario is one of a few California locations where L/CNG is currently provided. UPS refuels both LNG and CNG package-delivery vehicles at this site, and also offers a public-access side for both fuels. At stations like these with a large anchor fleet and high gas throughput, L/CNG can offer a cost-effective alternative to conventional CNG stations. According to GRI, the capital costs of a large (2,000 scfm) L/CNG station can be

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<sup>67</sup> John Veranicar, PG&E, personal communication to Jon Leonard.

<sup>68</sup> Peter Drake, personal communication to Jon Leonard.

<sup>69</sup> Jan Hull, personal communication to Jon Leonard and Rich Remillard.

<sup>70</sup> Transportation Research Board, *TCRP Report 38: Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations*.



nearly 50% lower than a conventional CNG station.<sup>71</sup> Operation and maintenance costs can also be significantly lower. However, there are relatively few existing L/CNG stations, and more information is needed to assess the long-term performance, reliability, and life-cycle costs of the L/CNG option.

### 2.6.3 Dispenser Systems and Fuel Metering

The performance, reliability and range of costs for CNG dispenser technologies all vary depending on the manufacturer, the intended application, the level of electronics sophistication, and other factors. According to a 1998 GRI study,

“A mature fuel dispensing infrastructure will include adequate fuel measurement and transfer equipment, facilities at the consumer interface, standardized design and installation of fueling stations, a diversity and density of fueling stations matched to consumer needs, and the ability to refuel vehicles that have run out of fuel away from a dispensing station.”

Natural gas dispenser technology is gradually being improved towards these goals, but more work needs to be done, especially to reduce costs. Currently, a two-hose fast-fill CNG dispenser with state-of-the-art fuel metering is priced in excess of \$30,000 – more than three times the cost of a competitive gasoline dispenser. Dispensers are second only to compression equipment as the most expensive part of a CNG fueling station. According to IGT, the cost of a gas flow meter accounts for 30% to 45% of the total dispenser cost. GRI and IGT are sponsoring ongoing efforts to develop improved, affordable fuel meters for CNG dispensers, with a near-term goal of commercializing two-hose dispensers at less than \$15,000.<sup>72</sup>

To some extent, dispenser costs are being reduced through greater standardization. The NGV1 standard for CNG dispensers was established in 1994 primarily for safety issues. It details construction and performance criteria for NGV fueling connections, specifically to prevent the fueling of a vehicle with lower service pressure by a dispenser station with a higher service pressure. NGV4 and ISO standards are now being established that will provide greater conformity for hoses and receptacles. However, more work is needed to standardize CNG dispensers, for both cost-saving and utility purposes.

The biggest cost determinant for CNG dispensers intended for public use may be weights and measures requirements at the federal, state, and local level. Dispensers for public CNG refueling facilities must meet National Type Evaluation Program (NTEP) Certification requirements, which can be very challenging in the case of gaseous fuels.<sup>73</sup> The cost to upgrade a single CNG station

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<sup>71</sup> *Natural Gas Fuels, Fueling Stations from A to Z*, article by David Port, May 1999.

<sup>72</sup> GRI Final Report #GRI-97/0398, *NGV Fueling Station and Dispenser Control Systems*.

<sup>73</sup> NTEP is fairly complex. The bulk of weights and measures enforcement authority rests with state and local

dispenser to NTEP standards can range from \$18,000 to \$25,000. One major difficulty in meeting the NTEP standards relates to the fact that CNG is treated more like a liquid fuel than a pressurized gas. The result is that the small volume of pressurized fuel that remains in a CNG dispenser hose at the end of a fueling event is sufficient to put the delivery accuracy out of compliance.<sup>74</sup>

Beyond this problem, more needs to be done to improve and standardize fuel metering. Today's fuel metering devices primarily rely on mass flowmeters that use Micro Motion Inc.'s technology based on the Coriolis effect. Most existing dispensers do not compensate for the cylinder gas temperature rise during fast fills or initial cylinder and station gas conditions. IGT has played a lead role in developing more sophisticated metering technologies that utilize temperature and pressure sensors, pressure-volume-temperature (PVT) relationships, and interaction with the vehicle fuel tank system to optimize fuel delivery. Emphasis is being put on improved temperature compensation routines because current technology often results in undercharged cylinders during fast fills. This reduces vehicle range, and users often try to compensate by overfilling the tank, creating pressures that exceed the recommended maximum pressure rating. GRI has recently developed and licensed a fast-fill algorithm to address complete filling of vehicle cylinders, and several dispenser manufacturers have integrated the technology into their products. The desired end of these various efforts is the commercialization of affordable dispensers that are equivalent to petroleum dispensers in performance. According to a recent study by Southwest Research Institute for GRI, this equates to a complete fill at the rate of 10 GGE per minute.<sup>75</sup>

Pinnacle has addressed the issue of poor temperature compensation and incomplete fills by offering dispenser technology that measures the interior temperature of the vehicle's CNG tanks during fast filling. Pinnacle claims that this system is unique and has arranged agreements with certain major CNG tank suppliers whereby thermocouples are pre-installed in the tanks.<sup>76,77</sup> This appears to be a viable approach to the problem, but ARCADIS Geraghty & Miller has been unable to confirm success of the Pinnacle system, due to lack of information. According to a spokesman for UPS in San Ramon (a major Pinnacle customer), the UPS CNG vehicles are equipped with this in-tank temperature measurement/compensation system, but as of March 1999 the system had not been hooked up to utilize this feature.

Flow rates through CNG dispensers could also be improved by larger tubing. In the absence of specifications for a sufficient minimum flow rate through CNG dispensers, "less reputable"

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jurisdictions, but federal requirements are sometimes utilized. For the sale of natural gas as a motor fuel, U.S. Weights and Measures requires an initial accuracy of +/- 1.5% with a +/- 0.6% repeatability.

<sup>74</sup> According to an executive from a major card reader company, and an executive from a turnkey CNG station company, who both requested anonymity.

<sup>75</sup> Southwest Research Institute, *NGV Fueling Station Technology Program: Final Report*, for Gas Research Institute.

<sup>76</sup> Drew Diggins, Pinnacle, personal communication to Jon Leonard.

<sup>77</sup> CNG vehicle outfitters are also including temperature measurement in the vehicle cylinders for a different reason: to improve the accuracy of the vehicle's fuel gauge.

packagers have been known to provide ¼ inch tubing instead of the ½ inch tubing considered to be the minimum diameter necessary for proper flow.<sup>78</sup> It should be noted that part of the problem with restrictive tubing sizes has been on the vehicle side. One conclusion of the Southwest Research Institute study for GRI was that vehicle manufacturers and conversion companies need to include larger and less restrictive fill lines from the vehicle receptacle to the vehicle cylinders so that faster fill rates can be achieved.

A few CNG station users expressed concern to ARCADIS Geraghty & Miller about the performance and reliability of CNG dispensers. Generally, however, issues such as incomplete fill volumes, lengthy fill times, or inability to fill multiple vehicles in sequence were not significant problems to these users. In part, this is probably due to the limited numbers of NGVs at most sites and the fact that fleets are usually able to stagger refueling events. Also, as previously noted, user knowledge is limited; many people were not familiar with the brand names or details of the fuel dispensers used in their system.

Installer/packagegers who were surveyed expressed definite preferences about dispenser technologies. Trillium USA and P.C. MacKenzie Corporation are among the installer/packagegers that favor CNG dispensers made by Tulsa Gas Technologies because they are medium priced, provide very effective temperature compensation during fast filling, and are capable of consecutively re-fueling many vehicles.<sup>79,80</sup> In part, TGT has benefited from technical assistance from GRI and IGT to improve its dispenser technology.<sup>81</sup> Sulzer makes a more expensive CNG dispenser that uses Gilbarco's dispenser frame and features the latest petroleum industry electronics. Fleetstar is among the CNG fuel providers that favors this Sulzer/Gilbarco technology.<sup>82</sup> Other installer/packagegers prefer CNG dispensers or dispenser components made by Krause, IMW Atlas, Apex, and DVCO. Procurement of cost-effective dispenser equipment for a particular CNG station is best accomplished by estimating the desired fueling capabilities for the intended application (allowing for possible fleet expansion), setting corresponding specifications, and then working with reputable, knowledgeable installer/packagegers. The availability and cost of critical replacement parts such as computer boards should be established up front. Also, some users may want to modify the dispenser's software program, so they should check in advance if the software is proprietary.<sup>83</sup>

## 2.6.4 Card Reader Systems

Card lock systems that control dispenser access and record and process NGV fueling transactions are available with many levels of sophistication. In selecting a particular system, users should consider the size of their fleet, where they will need to refuel (a remote location or on site), the

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<sup>78</sup> John Veranicar, PG&E, personal communication to Jon Leonard.

<sup>79</sup> Don Donaldson, Trillium USA, personal communication to Jon Leonard.

<sup>80</sup> Mark Good, P.C. MacKenzie Corporation, letter to Jon Leonard.

<sup>81</sup> Bill Liss, GRI, personal communication to Jon Leonard.

<sup>82</sup> Greg Dahl, FleetStar, personal communication to Jon Leonard.

<sup>83</sup> John Veranicar, personal communication to Jon Leonard.

types of records they need to maintain, and other criteria. Good discussions of the various types of NGV fueling transaction systems and their preferred applications can be found in two documents published by GRI: 1) GRI-95/0314, *Fuel Management Options for CNG Fueling Stations*, and 2) *Final Report, CNG Transit Fueling station Handbook*.

Stations equipped with the most sophisticated card lock systems -- networked card readers -- utilize a variety of payment cards and software. These systems may be more sophisticated than necessary for private stations but are generally considered essential for public-access stations. Currently, there are approximately 200 CNG fueling stations in California, of which about half are "public" stations. In most cases, it is necessary to establish separate CNG accounts with the operator(s) to fuel at these sites, which vary in their hours of access, equipment, payment method, and on-site assistance. According to the California NGV Coalition, it would require seven or eight different account cards to access all of the public CNG stations in California.<sup>84</sup> In Arizona, where currently at least four fuel-purchase cards are used, the problem is being addressed with a new requirement: all stations funded by government grants must install a card reader system that is compatible with Visa or Mastercharge.<sup>85</sup>

ARCADIS Geraghty & Miller focused on recent efforts to develop a networked system in California that will allow the use of a single fuel-purchase card. Card reader systems that have worked relatively well in California include E.J. Ward, AutoGas, GasBoy, and Petro Vend. Petro Vend, which is one of leaders in the fleet fueling business, claims to offer CNG card reader systems that are compatible "with a wide selection of commercial fueling networks" making operation of CNG dispensers as user-friendly as gasoline and diesel dispensers.<sup>86</sup> However, the E.J. Ward card reader system is probably the closest thing to a "universal" CNG fueling card in California. E.J. Ward has teamed up with the California NGV Coalition and Long Beach Gas & Electric Department to provide a common state-wide card link that will accept cards issued by San Diego Gas & Electric Co., Southern California Gas Co., Pacific Gas & Electric Co., Wright Express, Mesa (Pickens Fuel Corporation), GSA Fleet Management, Fleetstar, and the California Official State Credit Card. The E.J. Ward system is among the most advanced for having fully programmable, software-driven network capability, and is equipped with essentially universal card-reading capability.<sup>87</sup>

E.J. Ward's system is an important component of the FuelNet pilot program -- a networked system designed to develop card reader commonality among CNG stations. Targeted for initial deployment of this system are open-access, fast-fill stations that have adequate throughput capacity, a compatible card reader with dial-up modem, and are currently using the E.J. Ward system. FuelNet works by holding transactions in Random Access Memory at the card reader for downloading by a central computer, which stores the information in a database and generates

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<sup>84</sup> California Natural Gas Vehicle Coalition, *Fueling Stations Directory*, June 1997.

<sup>85</sup> GRI Final Report, *CNG Transit Fueling Station Handbook*.

<sup>86</sup> Petro Vend website (<http://www.petrovend.com/>).

<sup>87</sup> Greg Vlassek, California NGV Coalition, personal communication to Jon Leonard. Confirmed by industry sources.

billing statements. FuelNet is funded by numerous entities including GRI, DOE's Clean City Initiative, Atlanta Gas Light Company, the state of Georgia, and potential FuelNet users. Under phase I, FuelNet has been implemented at four sites in Atlanta, Georgia. For the last several years the California NGV Coalition has been working with DOE and certain California marketers to integrate California stations into the FuelNet system. Originally, it was hoped that FuelNet would be operational in California by 1997, but it has not progressed beyond a small pilot program.<sup>88</sup>

To some extent, the turnkey CNG station/fuel providers are investing capital and working with fuel card companies to improve card reader commonality at California CNG stations. Pinnacle is expanding its system to read credit cards such as Visa, much like card readers at most gasoline stations. Trillium USA's fueling cards provide 24-hour access to many private stations as well as all Trillium network stations. According to Trillium USA brochures, most commercial fleet fuel cards can also access Trillium USA's stations, making it "as convenient to fill up with CNG as it is to fill up with gasoline or diesel." Visa and Voyager are working on a joint partnership to process all fuel transactions, although the cost to upgrade existing card readers would reportedly be between \$5,000 and \$6,000.<sup>89</sup>

Despite these various efforts, the goal of card reader commonality may remain elusive. Major investments are required to advance card reader systems and improve commonality. With utilities constrained in using rate payers' money for such investments, private entrepreneurs must lead the way. Similar to the case regarding NTEP certification for dispensers, the main barrier involves lack of a compelling profit motive in the current CNG fuel and NGV markets. A sales representative from Petro Vend wrote the following to ARCADIS Geraghty & Miller:

"In response to your questions about CNG networks and standardization on a single card, my experience in the industry leads me to believe that there will be no "single" card or CNG-only national network until the number of vehicles and fleets using CNG is greatly expanded. There have been efforts made by various parties in Southern California to create CNG fueling networks and programs over the last several years. Even with the mandate that every government fleet over a certain number of vehicles convert a percentage of their fleet to alternative fuels, their efforts to create a regional network have not succeeded. Other regions have had varying degrees of success (ranging from some to none-at-all)."<sup>90</sup>

## 2.7 SETTING STATION SPECIFICATIONS

One of the biggest challenges for potential users of CNG stations is how to develop effective specifications for a competitive procurement process. The gas industry has taken a lead role in the attempt to develop standardized specifications for CNG stations, with mixed success. IGT has

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<sup>88</sup> EJ Ward website (<http://www.ejward.com/cng.htm>), quoting Greg Vlasek of Cal NGV Coalition.

<sup>89</sup> Greg Vlasek, California NGV Coalition, personal communication to Jon Leonard.

<sup>90</sup> Paul Nelson, Petro Vend, letter to Jon Leonard.

supported member efforts to develop software tools, such as CASCADE and NGV Gas Blend, which aid in understanding the design and operation of fueling stations and vehicles. In addition, BidSpec was developed to provide a cost-effective alternative for assembling bid specification packages for NGV fueling stations. Energy International is working on a CD ROM-based training and reference program entitled “NGV Fueling Station Advisor.” The initial unit is still in a “pre-Beta” form, although a web site is expected to be on line sometime in 1999.

In the absence of any standardized system, some CNG station procurements have contained extremely detailed specifications for every system component, essentially targeting a low-cost system by mixing and matching lower-priced compressors, gas storage systems, dryer systems, and so on. Some industry representatives believe that CNG stations picked using this method can result in poorly integrated systems that will cost more in the long run. The most effective procurements for CNG stations may be those that focus on simple, unambiguous performance specifications that essentially seek the lowest-cost quality CNG that can be reliably delivered to a given number of vehicles in a given amount of time. The following table<sup>91</sup> provides the type of information that fleets should be prepared to address in developing performance specifications for a CNG fueling facility:

Site Information	Location and size, subsurface conditions, availability and location of natural gas and electric utilities, suction pressure of natural gas line, potential need to expand facility; environmental regulations and sensitivities (emissions and noise).
Intended Application	Number, size and type of vehicles to be used; type of service (e.g., public transit, private package delivery).
Volume of Fuel Use	Anticipated short- and long-term gasoline (or diesel) equivalent fuel demand at station, including public users (if applicable).
Fuel Dispensing and Card Reader	Time-fill and fast-fill needs; projection of peak fueling needs; closed or open (public) access; type of fueling records and billing mechanism desired.
Project Scope	Responsibilities of the service provider; comprehensive description of services and equipment to be provided; expectations for start up and maintenance of station; payment and project-completion schedules.
Warranties	Equipment performance specifications; facility performance standards; response time for repairs; fuel quality standards (e.g., oil carryover).

## 2.8 NOISE CONCERNS

CNG compressor systems can emit unacceptable noise levels. As discussed above, large engine-drive compressor systems such as those used at transit districts may require noise-mitigation measures before they can be sited near noise-impacted areas. However, even the small, relatively quiet compressor systems can put out noise levels in the range of 50 dBA at under 20 feet. If these small units are installed near relatively quiet business areas or residential neighborhoods, and are placed in improper locations (such as between two close buildings or near a sound-reflecting

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<sup>91</sup> Derived from a PG&E brochure and revised to include other parameters.

surface), they can be significant nuisances. This could result in the enactment of local ordinances to prevent their use. Such problems could significantly set back efforts to expand use of NGVs.

## 2.9 IMPROVING USER KNOWLEDGE AND EDUCATION

As previously noted, the technical and economic nuances of CNG stations can be quite complex. GRI has acknowledged that “the traditional transportation industry” often has difficulty understanding these complicated factors. ARCADIS Geraghty & Miller’s informal survey has corroborated that NGV users often do not have good working knowledge about the equipment and systems that make up CNG fueling stations. For example, as indicated in Tables A-1 through A-12 in Appendix A, many of the surveyed users did not know the make and/or model of the compressor used in their system, or if a gas dryer was used. With the exception of gas company employees, few operators knew the site’s suction pressure or the critical relevance of that parameter to station design and operation issues. This lack of knowledge hinders wider implementation of a CNG refueling infrastructure in two key ways. First, objective, knowledgeable individuals are needed to select the best-available CNG fueling systems, especially since most stations must currently be customized for a particular site and application. Second, well-trained people are needed to maintain and operate the station, or much higher life-cycle costs and station downtime can result.

The Natural Gas Vehicle Institute (NGVI) in Las Vegas offers a series of forums and classes designed to educate the end users of NGV fueling systems. For example, twice annually the NGVI offers a three-day Natural Gas Fueling Station Technology Exchange as “an official forum for natural gas transportation fuel retailers to share common strategies, problem-solving techniques, design elements, and experiences.” Also twice annually, the NGVI offers its Natural Gas Fueling Station Operation & Maintenance Forum, which is specifically designed for people with hands-on responsibility for solving day-to-day O&M problems at natural gas fueling stations. Among the issues that are discussed are which lubricants are best for a given compressor, and how to determine if a given station needs a gas dryer.<sup>92</sup> In the past, dispersement of information from these NGVI seminars has been limited, but GRI and the NGV-IWG are now discussing making bulletins from NGVI’s Technology Exchange program available to all interested parties.

A third forum that NGVI offers is the Natural Gas Fueling Station Certification Course, which is a four-day program for public and private sector professionals involved with the design and operation of NGV stations. Successful participants receive a certificate verifying they have been trained in the latest fueling station technology. The curriculum includes permitting, codes and regulations, equipment, O&M plans, waste handling and disposal, and how to develop specifications.

Another effective way to help educate end users is to utilize the assistance of a reputable independent consultant (i.e., one who does not make equipment or sell fuel) in planning, sizing,

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<sup>92</sup> Natural Gas Vehicle Institute, website (<http://www.NGVI.com>).

specifying and procuring a CNG station. For example, Fuel Solutions in Santa Monica assists public- and private-sector vehicle fleet operators with objective analysis and recommendations regarding CNG infrastructure needs. They also provide comprehensive project management for CNG facility development, including specification development, RFP/bid management, contractor-award recommendations and vendor supervision.<sup>93</sup> Typically, Fuel Solutions charges between 6% and 10% of the total project cost to provide its comprehensive services. ARCADIS Geraghty & Miller surveyed CNG station operators who used the services of Fuel Solutions in obtaining their facility. As summarized in Table A-1 of Appendix A, all were satisfied with the services received, and believed that the money for an independent consultant was well spent.

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<sup>93</sup> Guthrie, Bruce, Fuel Solutions, personal communication to Jon Leonard; and Reb Guthrie, personal communication to Jon Leonard.



## SECTION 3 – CONCLUSIONS AND RECOMMENDATIONS

### *Standardization and Modularity*

- Today's CNG stations are still built "from the ground up" in customized fashion, with little commonality of parts, and limited capability to expand capacity in the future at relatively low cost. Some customization is essential to design an efficient and durable CNG station, but too much can result in an overly costly station that has more capability than necessary. This is a major barrier to expansion of the NGV refueling infrastructure.
- Greater standardization and modularization of CNG stations and equipment have been targeted to reduce costs and enhance commercial viability, but little tangible progress has been achieved to date. Site-to-site variations, especially in the suction pressure of the gas supply, are a major impediment to these goals.
- Government agencies should continue to work with GRI and the NGV-IWG to expedite greater degrees of standardization and modularity for CNG stations and individual components, especially compressor systems. Government funding for the installation of CNG fueling stations should be focused on mainstream applications at suction pressures where station customization can be minimized.

### *Importance of Well Packaged, Integrated and Maintained Systems*

- The success of a CNG station in terms of good performance, low life-cycle costs, and customer satisfaction largely depends on selection of a company with sound business and engineering credentials to plan and oversee its design, packaging, installation, and long-term servicing. Failure to use experienced, qualified vendors can result in a far-more-costly station than expected, or even one that is unusable.
- Competitive procurements for CNG stations should avoid using low bid as a major selection criterion. Packager/installers that consistently offer the lowest bid are unlikely to deliver reliable, cost-effective CNG fueling stations. In worst-case scenarios, such outfits have installed stations with inferior equipment and poor systems engineering, only to be out of business a few months later.
- Diligent verification of credentials is essential. To ensure that companies are qualified and in the CNG station business for the long term, bidders should be required to provide verifiable financial information and balance sheets. Packager/installers should be asked to provide a

detailed list of employee experience and every station installed over the last five years, with an emphasis on California installations.

- Prior to investing in a CNG station, users should establish performance specifications that clearly state their expectations for 1) refueling times and capacities as a function of fleet characteristics, 2) start up procedures and responsibilities for the facility, and 3) how essential maintenance items will be performed over the life of the station.
- Whenever possible, fleets should seek capital lease agreements in which a reputable turnkey company provides reliable, quality CNG at a fixed cost over a prescribed period of time, in return for a commitment to purchase a certain minimum volume of fuel (see life-cycle costs).
- If a comprehensive fixed-price agreement with a well-established turnkey company cannot be obtained, fleets investing in their own CNG fueling stations should carefully establish the services that will be provided upon station start up, using contract language such as the following: *Start up services shall be provided by a factory-authorized service technician for all major components. Proof of factory certification shall accompany quotation. After installation, service technician shall inspect all equipment, inspect site installation, place unit online, and prove operation and function of all controls. A laser alignment or equivalent of the prime mover and compressor shall be performed to ensure minimal bearing wear and system vibration. A service technician shall measure dew points at the station inlet and outlet to prove dryer function. On-site personnel shall receive at least one day of training in the proper operation and maintenance of equipment. Preventative maintenance procedures shall be established and a site-specific log shall be provided and reviewed.*<sup>94</sup>

#### *Public-Access Stations and Fuel Throughput*

- Low utilization of existing CNG stations and moderate overall fuel demand are the biggest barriers to a sustainable NGV fueling infrastructure. Expansion of the NGV market will depend on a significant increase in the numbers of high-throughput fueling stations, in tandem with a major increase in NGV demand.
- The incremental cost of building a fast-fill station that meets applicable codes and standards for public access can be extremely high. As long as there is low fuel throughput, industry executives have little or no incentive to make capital investments in public-access stations.
- Given this problem, the best use of government resources may be to help expand the CNG station infrastructure in applications that will currently deliver the most “bang for the buck” towards a sustainable market, i.e., large private fleets that use thousands of GGE per day.

#### *Fuel Quality*

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<sup>94</sup> Based on a composite of input from industry sources.

- Oil carryover from CNG fueling stations remains a significant but manageable problem in the NGV industry. The most sensitive NGV fuel systems can be adversely affected by oil carryover at 200 ppm or lower. Much higher oil concentrations have occurred at some CNG stations, causing NGV pressure regulators, valves, and other components to fail, and on-board CNG storage tanks to partially fill with oil.
- The effect of oil carryover on NGV emission levels is not well documented by the California Air Resources Board or the NGV industry.
- For most fast-fill CNG stations of mainstream size (200 to 300 scfm), the best oil-control solution appears to be the use of well-engineered lubricated compressors (e.g., Ariel or Sulzer brands) in tandem with synthetic polyalkylene glycol (PAG) oil and coalescing filters. On the downside, coalescing filters must be changed on a regular basis (more frequently with increasing fuel throughput), and filter disposal entails hazardous material issues.
- “Non-lubricated” compressors are available for use in mainstream NGV applications that effectively control oil carryover with advanced compressor designs (e.g., IMW Atlas’s crosshead cylinder configuration). These machines entail higher capital costs, but they offer other advantages that can offset such costs. Further documentation of non-lubricated compressor durability – especially ring life in real-world operation – may be needed to assess life-cycle costs compared to comparably sized, high-quality lubricated compressors.
- Smaller non-lubricated compressors are also commercially available for use at low-flow (<30 scfm) CNG stations, although most are designed only for low suction pressures. Several manufacturers (e.g., FuelMaker and Rix) of these units are focusing their engineering efforts on convenient, inexpensive ways to replace worn-out rings at the site, instead of more-costly technologies to extend ring life. These small compressor systems appear to offer good oil carryover control and performance at reasonable cost for certain applications not requiring multiple-vehicle fast filling.
- The NGV industry is taking steps to ensure that CNG-fueled vehicles are not harmed by oil carryover. Most NGVs are now equipped with coalescing filters that readily remove oil carryover in the liquid form, but they are less effective in removing vaporized oil.
- Small amounts of oil carryover (up to 70 ppm) are desirable for the fuel management systems of most NGVs; therefore, extremely pure CNG (e.g., “L/CNG” derived from LNG facilities) may have insufficient oil content to achieve effective system lubrication.
- Prospective packager/installers of CNG stations should be required to describe in detail the equipment, techniques and technologies they will employ to control oil carryover. Lubricated compressor technologies should use PAG synthetic oil and coalescing filters, or offer equally effective technologies. Detailed, real-world compressor ring-wear data should be provided for non-lubricated compressor technologies, and ring replacement procedures and costs should be described. All vendors should be required to provide a list of recent installations and the

names of customers who can verify that effective oil carryover control technologies are in place.

### *Moisture Content and Dryer Systems*

- Natural gas distributed in the US and Canadian piping networks often contains more water vapor than the recommended limit of 7 lbs per million standard cubic feet (MMSCF) of gas, and moisture spikes as high as 100 lbs per MMSCF can occur.
- Gas dryers made by Xebec and Pneumatic Products were most frequently recommended by end users and packager/installers that were surveyed. Stations without sufficient gas-drying equipment can produce high-moisture CNG that causes icing of NGV fuel systems during fueling, or moisture in ambient air can lead to icing. However, NGV manufacturers and station end users that were surveyed did not consider gas moisture and icing problems to be a major impediment to NGV operation.
- Problems with gas dryers at CNG stations are a significant source of high costs and station down time. Maintenance and regeneration of gas dryers (especially high-pressure twin tower automatic regenerative types) can be labor-intensive processes. Hazardous wastes from gas dryers add to the operating cost of a CNG station, and create potential health and safety issues with employees. For these reasons, many packager/installers avoid installing gas-drying systems in areas with relatively dry natural gas, and some end users are bypassing installed dryer systems. The decision to not employ gas-drying equipment at a CNG station can have significant cost implications and should be made only by experts.
- Problems with gas-dryer systems are exacerbated by inadequate training and knowledge on the part of station end users. Even large fleets with dedicated in-house service personnel may have insufficient expertise to effectively operate and maintain complex dryer systems.
- Whenever possible, comprehensive maintenance agreements should be executed with turnkey companies or other skilled personnel to rigorously maintain gas-dryer systems at CNG stations. End users that plan to maintain dryer systems themselves should seek training and/or expert advice (see section on user knowledge and education below).

### *Fuel Price*

- Many of the CNG station users surveyed were unsure of the price they pay for CNG, especially those who purchase raw gas and must calculate the costs of gas compression, operation and maintenance. Generally, fuel price has not been a factor in their satisfaction or dissatisfaction with NGVs and CNG fueling stations.
- Gas utilities set the price of natural gas according to unique tariffs and pricing structures, which has resulted in a wide range of CNG prices. Private-sector turnkey providers set the price of CNG as a function of the raw commodity cost and whatever the market will bear after

the costs of compression, O&M, and profit are added. However, the most important determinant for CNG pricing is station throughput. Some turnkey companies will not build stations without at least one “anchor tenant” who will commit to purchasing large volumes of fuel over several years time.

- The typical price of CNG at California’s public access stations is currently about \$1 per GGE. This will be significantly reduced if Congress passes the recently introduced Alternative Fuel Promotion Act, which will give CNG sellers a 50 cents per GGE tax credit.
- Private-sector turnkey CNG providers prefer that government agencies focus on helping fleets obtain reliable compressed fuel at the lowest price, without being involved in pricing structures.

#### *Station Life-Cycle Costs*

- No clear blueprint exists for builders of CNG fueling stations to achieve the \$1,000 per scfm capital cost that has been targeted by GRI and the NGV-IWG. Standardization of components like compressors and dryer systems is a key strategy to reduce capital costs, but wide variations in site-specific parameters currently lead to high levels of customization, and associated higher costs.
- O&M costs must also be significantly reduced to make CNG stations cost competitive with liquid fuel stations on a life-cycle basis. Major factors in keeping O&M costs to a minimum are 1) selecting the best-suited equipment for the intended application and 2) implementing a comprehensive preventative maintenance program that will ensure the reliability of that equipment for the useful life of the station.
- The most fundamental equipment choice is whether to use an electric motor or an internal combustion engine as the prime mover to power gas compression. Both options offer certain advantages and disadvantages, depending on the intended application and other factors. Generally, smaller CNG stations are better off utilizing electric motors, trading off the higher cost of electricity for lower capital and maintenance costs. For larger CNG stations with high gas throughput where a rigorous preventative maintenance program is in place, the higher cost of electricity for gas compression may make gas engine drive more attractive.
- However, a major downside of gas engine prime movers can be the expense, time and difficulties associated with air quality permitting and compliance. Control-logic problems have occurred with large stationary source engines used in CNG applications, resulting in out-of-compliance NO<sub>x</sub> levels that have severely limited operating time. Prospective users of engine-drive systems should carefully check local air quality permitting rules and make sure that the engine is equipped with electronic controls geared for low NO<sub>x</sub> levels over the intended duty cycle.

- The dilemma of how to properly maintain a CNG station can pose difficult problems for many fleets. Many public-sector operators simply don't have the appointed people to maintain a complex fueling station. Affordable service agreements for existing stations can be difficult to obtain. The end result is that many CNG stations do not get the necessary maintenance to operate reliably and at reasonably low O&M costs.
- Noise can also be a significant cost issue for engine-drive prime movers. Costly noise enclosures may be necessary, and heat-dissipation problems can result. Careful consideration of noise attenuation costs should be addressed before siting CNG stations, especially near residential areas.
- Vibration of the prime mover (especially at larger CNG stations) can result in poor alignment with the compressor, which in turn can cause a high rate of bearing wear and other problems. Installer/packers should be required to describe how they will guarantee precision alignment of the prime mover and compressor (e.g., laser alignment) at the station's initial installation, and throughout its useful life.
- Fleets with very large throughputs of CNG fuel are increasingly executing agreements with reputable and experienced turnkey CNG companies to purchase prescribed volumes of fuel, under all-inclusive service and operating contracts. These are fixed-price commitments (inflation included) that can put less risk on the end user and provide accurate costs for a new CNG station over a set time period. Virtually all the problem issues noted above can be addressed through these arrangements, and major savings can be realized by the customer. Government agencies should encourage and assist such arrangements as much as possible.
- In addition, government assistance and funding should be used to help pool the resources and fuel demands of smaller fleets. This will help attract CNG station bids by turnkey companies that require minimum fuel volumes to obtain a sufficient return on investments.

#### *CNG from LNG Stored On-Site (L/CNG)*

- CNG derived from LNG stations (L/CNG) offers several advantages over conventional CNG, and life-cycle costs of L/CNG facilities can be significantly lower. However, not much operational experience on L/CNG has been accumulated in California, and more information is needed to assess long-term performance, reliability, and life-cycle costs.

#### *Dispenser Systems and Fuel Metering*

- The performance, reliability and range of costs for CNG dispenser and metering technologies vary depending on the manufacturer, the intended application, the level of electronics sophistication, and other factors. Technologies are gradually being improved but more work needs to be done to reduce costs. Dispensers are second only to gas compression equipment as the most expensive part of a CNG fueling station.

- Gas flow meters account for much of the total dispenser cost. Efforts are underway to improve and standardize fuel metering, with better compensation for the heat of compression to ensure complete fills. GRI has recently developed and licensed a fast-fill algorithm to address complete filling of vehicle cylinders. Private companies are also attempting to improve cylinder filling (e.g., Pinnacle's dispenser that compensates through measurement of interior CNG tank temperature during fast filling).
- CNG dispensers intended for public-access stations must meet challenging and expensive Weights and Measures (W&M) regulations, including National Type Evaluation Program (NTEP) certification that may impose requirements not fully germane to gaseous fuels. Government agencies with vested interests in expansion of the CNG infrastructure should consider working with the dispenser industry and W&M officials to investigate this further.
- Most fast-fill station users who were surveyed were concerned about the cost of CNG dispensers, but found dispenser performance (fill times and completeness) and reliability to be acceptable. Among the dispenser brands receiving recommendations from users and packer/installers were Tulsa Gas Technologies and Sulzer.
- Reliable, cost-effective dispensers are best procured by carefully assessing the intended application and vehicle fill requirements, and then working with reputable, knowledgeable installer/packagers to choose the best make and model. Availability and cost of critical replacement parts such as computer boards should be established up front. Tubing diameter of at least ½ inch should be required. Users who may want to modify the dispenser's software program should check in advance if the software is proprietary.

### *Card Reader Systems*

- Card lock systems that control dispenser access and record and process NGV fueling transactions are available with many levels of sophistication. In selecting a particular system, users should consider the size of their fleet, where they will need to refuel (a remote location or on site), the types of records they need to maintain, and other criteria.
- Stations equipped with the most sophisticated card lock systems, networked card readers, utilize a variety of payment cards and software. Recent efforts to develop a networked system in California that will allow the use of a single fuel-purchase card have been only moderately successful.
- The E.J. Ward card reader system is among the most advanced for fully programmable, software-driven network capability. E.J. Ward's system is an important component of the FuelNet pilot program -- a national networked system designed to develop card reader commonality among CNG stations. The California NGV Coalition is now working with vested interests to integrate California stations into the FuelNet system. To a limited extent, the turnkey CNG providers are also working with fuel card companies to improve card reader commonality at California CNG stations.

- Despite these various efforts, card reader commonality is likely to remain elusive due to the magnitude of the required investments. Executives from the CNG fuel card industry indicate that the market for CNG fuel must be greatly expanded before they are willing to invest the necessary capital to make a universal card reader system.

#### *Setting Effective Station Specifications*

- The CNG industry is actively attempting to develop improved mechanisms for specifying CNG stations in simpler, more standardized terms. Programs such as CASCADE, NGV Gas Blend, BidSpec, and NGV Fueling Station Advisor are being developed. Success has been mixed, and it is premature to fully evaluate the utility of these various efforts.
- In the absence of any standardized system, CNG station procurements sometimes contain extremely detailed specifications on every station component instead of an overall station performance specification. Some surveyed industry representatives believe that CNG stations picked in this fashion are likely to result in poorly integrated systems that will cost more in the long run.
- Whenever possible, procurements for CNG stations should focus on simple, unambiguous performance specifications that essentially seek the lowest-cost quality CNG that can be reliably delivered to a given number of vehicles in a given amount of time.

#### *Noise Concerns*

- Even smaller CNG compressor systems can emit unacceptable noise levels. Careful attention should be given to noise levels, the intended application, and placement of the compressor unit when stations are installed in noise-sensitive areas. Lack of attention to such problems could hinder expanded commercialization of the CNG infrastructure and natural gas vehicles.

#### *Improving User Knowledge and Education*

- The technical and economic nuances of building and operating CNG stations are complex, largely due to the high degree of customization that routinely occurs. Even end users with trained technical personnel can have difficulty understanding these complicated factors. Lack of knowledge by users contributes significantly to high station life-cycle costs, and hinders wider implementation of the CNG refueling infrastructure.
- Government funding and resources can be used to improve the knowledge of existing and prospective end users of CNG stations. For example, the Natural Gas Vehicle Institute (NGVI) offers a series of forums and classes such as Natural Gas Fueling Station Technology Exchange and Natural Gas Fueling Station Operation & Maintenance Forum. Attendees can be comprehensively educated on specifying, selecting, permitting, operating, and maintaining CNG fueling stations. It is expected that the NGVI will be working with GRI and the NGV-



IWG in the near future to expand outreach of this valuable information, and California's government agencies should follow up on this opportunity.

- Another effective way to help educate end users is to utilize the assistance of an independent consultant in specifying, bidding, selecting and even operating a CNG station. For a fee (typically between 6% and 10% of the total project cost), companies such as Fuel Solutions provide public- and private-sector vehicle fleet operators with objective analysis and recommendations regarding CNG infrastructure needs, including comprehensive project planning and management. Government funding can be used to help fleets defray the cost of using such consultants.



## APPENDIX A – USER SATISFACTION TABLES

### NOTE:

*The following tables summarize information and opinions provided to the authors by the cited individuals during brief telephone discussions on the date(s) indicated in Appendix B. Survey techniques to select the contacted users were not scientific. Attempts were made to speak to the most knowledgeable person available at a given end-user's site, but that was not necessarily achieved. **The individual views expressed in these tables are not necessarily representative of other end users' experience with the cited company's equipment and/or services.** At best, these tables provide snapshots of user "satisfaction" for a given system by a single individual at the time they were contacted. Part of the purpose of the survey was to assess the level of user knowledge about the CNG systems that they operate and/or maintain. Verification of the information provided (such as system specifications and equipment type) was therefore not attempted.*

## APPENDIX B: REFERENCES AND SOURCES OF INFORMATION

- Bacyinski, Rob, MichCon Gas Company (Sulzer user), 313-256-5121, personal communication to Jon Leonard, 02/22/99
- Barker, Tom, Alternative Fuel Technical Specialist, Ford Motor Company 313-337-5339, personal communication to Jon Leonard, 02/18/99
- Branner, Jim, Cummins Engine Company, e-mail to Jon Leonard, 01/15/99
- California Natural Gas Vehicle Coalition, *Fueling Stations Directory*, June 1997.
- Cowan, Paul, Ford Motor Company, AFV Department, personal communication to Jon Leonard, 02/15/99
- Cundiff, George 614-460-2239 Columbia Gas Company (Krause and Hurricane users), personal communication to Jon Leonard, 02/24/99
- Dahl, Greg, FleetStar (Sulzer user), personal communication to Jon Leonard, 02/17/99
- Diggins, Drew, Pinnacle Corporation, personal communication to Jon Leonard, 1/14/99 and 2/16/99
- Donaldson, Don, Trillium USA, personal communication to Jon Leonard, 2/12/99
- Drake, Peter, General Manager, South Coast Area Transit, personal communication to Jon Leonard, 3/1/99
- EJ Ward, website (<http://www.ejward.com/cng.htm>)
- Energy Information Administration/Natural Gas Monthly April 1999, *Natural Gas 1998: A Preliminary Survey*, Table SR1, p. xvii.
- Freeman, Brett, Royal Lubricants Company, personal communication to Jon Leonard, 2/11/99
- Fu, Warren, Los Angeles County Metropolitan Transit District, personal communication to Jon Leonard, 3/1/99
- FuelMaker Corporation, product information sent by Paula Hebert.

Gandalf, Dave, City of West Covina (Fuel Solutions client), personal communication to Jon Leonard, 2/4/99

Gas Research Institute, Abstract for GRI-95/0483, *NGV Fueling Station Oil Control*, from GRI website

Gas Research Institute, *Case Studies of Cost-Effective Natural Gas Fueling Stations*, (no publishing information provided on document).

Gas Research Institute, Final Report GRI-97/0398, *NGV Fueling Station and Dispenser Control Systems*, Prepared by Prepared by Institute of Gas Technology, Des Plaines, Ill., November 1997.

Gas Research Institute, *Final Report, CNG Transit Fueling station Handbook*, GRI, February 1997, Prepared by Wilson Technologies, Santa Fe Springs, CA an the Marathon Compressor Company Ltd., Heidelberg, Ontraio, Canada.

Gas Research Institute, Final Report, GRI-96/0201, *Propane-Air Peakshaving Impact on Natural Gas Vehicles*, from GRINet and GRI web site.

Gas Research Institute, GRI-96/0028 Topical Report, October 1993-June 1996, *Gas Composition Issues and Implications for Natural Gas Vehicles and Fueling Stations*, from GRI website [http://www.gri.org/subscriber/content/aug/19980820/161511/96\\_0028-06.htm](http://www.gri.org/subscriber/content/aug/19980820/161511/96_0028-06.htm).

Gas Research Institute, *Report on National NGV Infrastructure*, GRI Contract No. 5097-940-3872, August 10, 1998, prepared by Battelle Columbus Operations / Pacific Northwest National Laboratory

Gas Research Institute, GRI Tech Profile #97/0226, *FuelMaker-Quantum Products More Economical with Increased Service Service Interval*, August 1997.

Gas Research Institute, Topical Report GRI-95/0314, *Fuel Management Options for CNG Fueling Stations*, Prepared by the Marathon Compressor Company Ltd., Heidelberg, Ontario, Canada, August 1995.

Goeringer, Larry 209-233-5136, Visa Petroleum (Sulzer user), personal communication to Jon Leonard, 2/22/99.

Golden, John, City of Scottsdale, Fleet Director (Trillium USA user) personal communication to Jon Leonard, 02/19/99

Gomez, Jose, California Air Resources Board, personal communication to Jon Leonard, 02/11/99.

Good, Mark W., President, P.C. McKenzie Company, phone call on 1/29/99 and 2/1/99 letter to Jon Leonard

Gray, Terry, Vineyard Engine Systems, 210-520-7924, 2/11/99 (no reply)

Grimmer, Curt, Hurricane Compressors, personal communication to Jon Leonard, 02/22/99 and information package sent

Guthrie, Bruce, Fuel Solutions, personal communication to Jon Leonard, 01/14/99

Guthrie, Reb, Fuel Solutions, personal communication to Jon Leonard, 02/17/99

Harger, Jim, Pickens Fuel Corporation, meeting with Jon Leonard, 1/7/99

Haught, Mark, Southwest Gas Company (Trillium USA and Sulzer users), personal communications to Jon Leonard, 1/25/99 and 2/22/99

Hawthorne Power Systems, *CAT Service Engineer Technical Report* by Mike LeClair, 07/24/98, provided by Peter Drake of South Coast Area Transit.

Hebert, Paula, FuelMaker Corporation, personal communication to Jon Leonard, 02/16/99.

Hempelman, Ed, Southwest Gas Company (Trillium USA and Sulzer users) 602-395-4139, personal communication to Jon Leonard, 2/22/99

Hewatt, Rick, Checker Cab Company (FuelMaker user), personal communication to Jon Leonard, 02/17/99

Hughes, Paul, California Air Resources Board, personal communication to Jon Leonard, 2/11/99

Hull, Jan, Vice President, Trillium USA, personal communication to Jon Leonard and Rich Remillard, May 26, 1999.

IMW Atlas, Inc., from IMW Atlas website (<http://www.imwcng.com>).

Jerry Wells, Chrysler Canada (Trillium USA user), personal communication to Jon Leonard, 02/15/99.

Johnson, Bruce, Impco Technologies, 562-860-6666, personal communication to Jon Leonard, 2/11/99

Jones, Steve, Director of National Sales, Ingersoll Rand Corporation, 1/28/99

Kawalski, Mike, Plant Engineering Supervisor, United Parcel Services (IMW Atlas user), 860-275-1932, personal communication to Jon Leonard, 2/18/99

Knight, Ben, Vice President of Honda R&D Americas, personal communication to Jon Leonard, 2/12/99

Knox Western Company, *Vehicle Fueling Applications*, from Knox Western website (<http://www.eeknoxair.com>).

Lebra, Steve, Willamette Industries, Inc. (IMW Atlas user), personal communication to Jon Leonard, 02/15/99

Liss, William, Team Leader, Energy Conversion, GRI, letter to Jon Leonard dated 1/19/99

Long Beach Gas & Electric Department, website (<http://www.ci.long-beach.ca.us/gas/rate5.htm>)

Maciel, Amando, City of Hawthorne (Fuel Solutions client), personal communication to Jon Leonard, 2/4/99

MaClennan, Malcom, Kraus Corporation, personal communication to Jon Leonard, 2/18/99

Marelli, Mike, Mesa Pacific, personal communication to Jon Leonard, 1/25/99

Martin, David, Project Engineer, Stuart Energy Systems, meeting with Jon Leonard on 2/9/99

McCarthy, Paul, United Parcel Services (IMW and Pinnacle user), personal communication to Jon Leonard, 02/17/99

McElvery, Hank, Sulzer USA, meeting with Jon Leonard, 1/22/99

Miller, Mike, Sacramento Housing Authority (FuelMaker user), 916-566-1245, personal communication to Jon Leonard, 2/17/99

Myers, Kimberly, Natural Fuels Corporation, personal communication to Jon Leonard, 02/16/99

Name withheld by request (executive for major card lock company), personal correspondence (e-mail) 02/24/99.

Natural Gas Fuels, *Fueling Stations from A to Z*, article by David Port, May 1999.

Natural Gas Vehicle Coalition, *Natural Gas Vehicle Industry Strategy*, undated report, PDF downloaded on 6/4/99 from website (<http://www.ngvc.org/strategy.pdf>).

Nelson, Paul, Sales Representative for Petro Vend, letter to Jon Leonard dated 02/26/99

Paul, Diann, City of West Covina (Fuel Solutions client), personal communication to Jon Leonard, 02/04/99

Pearce, David, Sulzer USA, personal communication to Jon Leonard, 1/7/99

Petro Vend Corporation, web site (<http://www.petrovend.com/>)

Pope, Gary, Consultant, personal communication to Jon Leonard, 1/29/99

Richards, Larry, Maintenance Supervisor at OmniTrans, personal communication to Jon Leonard, 2/26/99

Rossi, Carmen, Consultant / Chair of NGV1 Committee, personal communication to Jon Leonard, 2/16/99

Rowand, Jeremy, Managing Director, Gemini Compressors, e-mail to Jon Leonard on 3/09/99.

Royer, Rebecca, President of BayTech Corporation, personal communication to Jon Leonard, 2/17/99

San Diego Gas & Electric, website (<http://www.sdge.com/>)

Sayre, Bill, VP of Operations, IMW Atlas, 502-584-7766, personal communication to Jon Leonard, 2/18/99

Shay, Micheal, City of Redondo Beach (Fuel Solutions client), personal communication to Jon Leonard, 2/4/99

Shimer, John, AutoGas, personal communication to Jon Leonard, 2/23/99

Shugart, Ginger, Assistant Administrative Analyst, Long Beach Gas and Electric Department, personal communication to Jon Leonard (e-mail), 03/03/99

Sinclair, Stan, Southern California Gas Company, personal communication to Jon Leonard (email), 2/24/99

Smith, Ron, Southern California Gas Company, personal communication to Jon Leonard, 2/23/99

Society of Automotive Engineers, SAE J1616 Standard

Southwest Research Institute, *NGV Fueling Station Technology Program: Final Report*, for Gas Research Institute, from GRInet, GRI website.

Sparks, Greg, Electrical Engineer, Portland International Airport (IMW Atlas user), personal communication to Jon Leonard, 02/16/99

Stover, Smokey, Northwest Natural Gas Company (IMW Atlas user), personal communication to Jon Leonard, 02/16/99

Taylor, Jay, Southwest Gas Company, personal communication to Jon Leonard, 1/25/99

Transportation Research Board, *TCRP Report 38: Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations*, written by ARCADIS Geraghty & Miller, National Academy Press, 1998.

Trillium USA, *Reciprocating Compressors: Lubrication vs. Non-Lubrication*, by Michael B. Riordan, P.E., 1/12/97.

Usner, George, Columbia Gas Company (Krause and Hurricane user), personal communication to Jon Leonard, 02/22/99



Veranicar, John, Pacific Gas & Electric, personal communication to Jon Leonard, 1/29/99

Vlasek, Greg, California Natural Gas Vehicle Coalition, personal communication to Jon Leonard, 01/05/99

Waldner, David, Los Angeles International Airport 310-646-3263, personal communication to Jon Leonard, 02/26/99

Walker, Terry, Checker Cab Company (FuelMaker and Gemini user), 404-351-8255 ext. 114, personal communication to Jon Leonard, 02/17/99

White, Nick 416-340-1040, CNG consultant, Toronto, Canada, personal communication to Jon Leonard,, 2/3/99

Yee, Gary, California Air Resources Board, information faxed on 1/15/99

Young, Harold, Gilbarco Corporation, personal communication to Jon Leonard, 01/08/99